Mechanical Inspection

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MECHANICAL INSPECTION

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MECHANICAL INSPECTION

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III

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FOREWORD

The Pennsylvania State University Industrial Series includes texts in mathematics, mechanics, strength of materials, and physics. These books have been written by faculty members of the College of Engineering and Architecture. On occasion the texts have been of value in undergraduate instruction but their principal purpose is for use in technical institute and industrial training courses. Frequently the students in these classes are adults and sometimes they pursue their education on a part-time basis. Direct, simple textbooks with a practical approach are of considerable aid in conducting successful instruction for these students.

The Department of Engineering Extension of The Pennsylvania State University has engaged in the conduct of educational programs for industrial groups continuously since 1912. During this period of 40 years numerous resident faculty members have been responsible for the development of suitable course outlines and supplementary instructional materials for extension courses. Too few textbooks have been written for instruction on the technical institute level and thus it has been necessary to resort to the use of individually prepared notes for source material. Most of the books in the industrial series have evolved from instructional material prepared for engineering extension courses.

"Mechanical Inspection" is no exception in the history of its

development. Professor W. H. Armstrong has served for many years on the faculty of the Department of Industrial Engineering and has been responsible for much of the instruction and laboratory work in the teaching of industrial processes. During the Second World War Professor Armstrong assisted the Department of Engineering Extension in providing suitable course material for hundreds of specialized inspection classes conducted as a part of the Engineering, Science, and Management War Training Programs. During the postwar years he developed additional materials on inspection and quality control for use in the Penn State Technical Institutes.

It is hoped that this book will play an important part in the training and education of skilled mechanics, technicians, and engineering aides engaged in the metalworking industries. Its approach is a practical one and the integration of essential basic information in mathematics and blueprint reading should prove to be an asset.

K. L. HOLDERMAN
Professor and Director of Engineering Extension

1

INTRODUCTION

Inspection is the process of examining the raw materials, work in process of manufacture, and finished goods of industry to ascertain whether they conform to or deviate from the standards of quality that have been specified for them. The principal reasons for inspection at various stages in the manufacturing process are:

1. To prevent accepting shipments of, and starting work on, raw materials that do not agree with specifications.
2. To prevent doing further work on material that was spoiled in an earlier process or operation.
3. To locate manufacturing processes that are producing or are tending to produce defective work because of mechanical or human failure as a preliminary to correcting the cause.
4. To prevent delivery of defective products to customers.

Organization for Inspection

The organization for inspection in any plant depends on the product, the method that is used to produce it, and the quantity that is to be produced.

Organization in small plants

Shops that are engaged in small-lot production use general-purpose tools in manufacturing and employ skilled workmen to operate them. The work is measured with standard tools, and parts of the product that require careful fitting are made to agree with

each other. The final assembly of the product is depended on to disclose faulty materials and workmanship in components and to provide an opportunity to correct any defects that are found. A final operating or usage test serves as the means of judging the design and functioning of the product. In this system of production, each workman acts as the inspector of his own production to a great extent, and he checks the workmanship done previously on all work that he handles.

Organization in mass-production industries

The organization for manufacturing and inspection in mass-production industries is quite different from that which was described in the preceding paragraph. Standardized products and components, interchangeable and selective assembly methods, and extreme division of labor are highly developed in these industries. Special semiautomatic and fully automatic machines are used in production, and workers with a minimum amount of training and skill are employed to operate them. Frequently, a workman simply feeds or unloads a machine without either understanding the machine's operation or knowing the function of the part that he handles. Therefore, he is unable to exercise judgment regarding the operation that he controls or the quality of the work which he produces. If he measures the work at all, he does it with special gages that show if the product measures within limits of variability which are specified for it. When defective articles are produced, he stops the process until a setup man can adjust the machine. In many instances, the workman is paid an incentive wage, that is, he is paid for quantity and not quality of production. As a result of these conditions, there is a tendency toward a progressive deterioration of quality in mass-production industries; and since there is no provision in interchangeable- and selective-assembly manufacturing for detecting and correcting faulty workmanship during the assembly operation, these industries establish inspection departments to examine the quality of components, subassemblies, and final assemblies at every stage of their manufacture.

Various combinations of the two systems of production and inspection that have been described may be employed to suit the conditions in any manufacturing plant.

Quality Standards

The standards that are used to judge industrial materials and products are usually described in blueprints and their accompanying bills of material. Sometimes, a written specification, or a sample, or both are also required to describe a product adequately to the workmen and inspectors in a plant. Characteristics that must be examined and methods that are used to inspect them are:

1. Number or quantity: Physical count, weight, or volume.
2. Chemical composition and physical properties: Chemical analysis, and physical tests of strength, elasticity, hardness, etc. These specifications are usually employed to describe raw materials such as pig iron, castings, and bar stock; and most manufacturing plants can accept such materials from their producers with little or no inspection. When requirements are severe, however, laboratory examination of each lot that is received may be necessary. When a shop process affects one of these characteristics or properties, as in the case of heat treatment and its effect on the hardness of steel, a laboratory test may be employed for routine inspection in the plant.
3. Dimensional characteristics: Linear and angular measurements. Most machine-shop inspection falls in this category.
4. Surface geometry: Visual and tactile examination with unaided senses or with instruments.
5. Surface and subsurface soundness: x-ray and magnetic-particle inspection.
6. Performance: Running or usage test.

The Inspection Department

In most manufacturing plants, the inspection function is performed by inspectors who are organized in a department under a chief inspector. When quality is of primary importance, the chief

inspector should be responsible to the head of the engineering department or to the general manager of the plant. But when it is not of first importance, he may be answerable to the plant superintendent. The first arrangement is preferable for assuring quality because, under it, the inspection department is independent of producing departments; and conflicts between quality and quantity production will be resolved by an authority that is not biased in favor of either.

Kinds of Inspection

It is most economical to discover defective materials and workmanship as early in the productive cycle as possible, and with a minimum amount of inspection. Consequently, different kinds of inspection have been devised to accomplish this in various manufacturing situations. The most important are:

1. *Sorting or acceptance inspection.* This kind of inspection is for the purpose of classifying the product as good or bad and is used to decide on the disposition of defective units by rework, salvage, or scrap. These decisions should be based on the economic advantage of one proposal over the others.

2. *Inspection by attributes.* This is inspection to determine if a product does or does not possess a specific characteristic or attribute.

3. *Inspection by variables.* This is inspection with a graduated measuring instrument to determine the actual size of the work within the limit of accuracy inherent in the measuring tool.

4. *One hundred per cent inspection.* When no defective units are permissible, one hundred per cent inspection of a product is necessary. Every unit must be measured. However, even this will not assure perfection because there is always the possibility of error by the inspectors due to the tedious and fatiguing nature of the work.

5. *Sampling inspection.* This kind of inspection is performed on a random sample that is drawn from a lot of the product. The sample is considered to be representative of the entire lot; and the lot is accepted, inspected further in some cases, or rejected as the result

of the examination. This procedure may be employed in either of two situations: first, when some defective units of the product are permissible and it is desired to reduce the cost of inspection by examining a minimum quantity of the article; and second, it is a necessary procedure when the nature of the test destroys the product. It should be noted, also, that sampling inspection may be more effective than one hundred per cent inspection for assuring quality because it reduces the tedium and fatigue involved in the operation.

6. *Centralized inspection.* Comparatively small and light parts, subassemblies, and final assemblies of the product are transported to an inspection department for examination. Usually, the department is located in a room that is separated from the manufacturing areas of the plant so that the work and inspection tools can be cared for properly and so that the operation may be performed without interference.

7. *Floor inspection.* Parts and assemblies that are too large or heavy for transportation to a centralized inspection department are examined by inspectors who go to the production centers where the work is located.

8. *First-piece inspection.* After a semiautomatic or fully automatic machine has been set up to do a job, a trial piece is produced and inspected. If inaccuracies are discovered, the machine is adjusted, and another trial piece is made. When a trial piece passes inspection, the machine is released for a production run.

9. *Pilot-piece inspection.* When operations on more than one machine are required to complete a component, a trial piece is run through all of them. After a pilot piece has passed inspection, the production line is released for a run.

10. *Working inspection.* After a single machine or a production line has been released for a run, as in (8) and (9), the work may be inspected periodically by a traveling inspector to disclose any trend toward the production of defective units caused by worn tools or altered machine adjustments. If such a condition is discovered, the machine or line is shut down until it has been corrected. This is a

form of sampling inspection in which the principle has been extended to prevent the production of defective work.

11. *Key-operation inspection.* Work is inspected before and/or after critical or expensive operations so that additional effort on defective units may be avoided.

12. *Performance inspection.* Components, subassemblies, and final assemblies of a product are usually given a final examination before they are released to the stock department or customer. This may consist of:

a. Functional inspection. A machine may be operated in either the manufacturer's or the customer's plant to see that it performs according to specifications.

b. Efficiency inspection. Engines, pumps, and similar machines may have their performances checked with instruments to see that they develop rated horsepower or other specified characteristics.

13. *Endurance inspection.* Automobiles and other machines are taken from assembly lines and operated for a specified time or until failure occurs. Then they are disassembled, and the components are inspected to discover the effects of use. This inspection is for the benefit of the engineering department that uses the information which is obtained to improve the product through the specification of better materials, processes, and designs.

Qualifications of an Inspector

An inspector should have certain qualifications if he is to do his job effectively. Technical knowledge and skills that he should possess consist of:

1. The ability to read blueprints.

2. The ability to make mathematical calculations in connection with some inspection operations. In most cases, the ability to apply a simple formula and some preparation in trigonometry are all that are required.

3. A knowledge of terms that are used in connection with the

"process of measuring manufactured materials to assure the specified uniformity of size . . . required by . . . industries."[1]

4. A thorough understanding of, and an ability to use the inspection tools that are described in this manual and others of a similar nature that are not explained for lack of space.

QUESTIONS

1. Define the term "inspection."
2. What are the principal reasons for inspecting work at various stages in the manufacturing process?
3. Explain why the organization for inspection differs in (*a*) job-lot industries, and (*b*) mass-production industries.
4. Name three ways of describing the qualities that are wanted in industrial materials and products.
5. Name the principal characteristics that are examined when judging the qualities of industrial products.
6. Name the most important kinds of inspection that have been devised, for use in various circumstances, to discover defective materials and workmanship as early in the production cycle as possible.

[1] Extracted from "Tentative American Standard Tolerances, Allowances and Gages for Metal Fits" (ASA B4*a*-1925), with the permission of the publisher, The American Society of Mechanical Engineers, New York.

2

BLUEPRINT READING

The ability to read blueprints is usually a qualification that is required for employment as an inspector.

A *blueprint* is a photographic copy of an original working drawing that is made with a pencil or pen on tracing paper or cloth. This working drawing is a conventionalized representation of an industrial product or its components, drawn to scale, that gives information about the shape, dimensions, and other details of the product to those who are engaged in manufacturing and inspecting it. Since a working drawing is a symbolic representation of an object, it is necessary for the user of such a drawing to interpret what he sees; and the process of interpretation is called "reading a blueprint" or "blueprint reading."

The principal conventions that are employed in making drawings consist of (*a*) representing an object by means of views that are placed in a standardized relationship to each other, (*b*) the use of lines that have specific characteristics for definite purposes, (*c*) the use of sectional drawings to show interior construction of some objects, and (*d*) symbolic representation of certain standard details.

Pictorial Representation

A picture (Fig. 2.1) represents an object as it is seen by the eye; a pictorial drawing (Fig. 2.2) presents a close approximation of its

actual appearance. Pictures like these, however, do not give workmen enough information about industrial products to permit their manufacture and inspection. Therefore, a system of drawing called

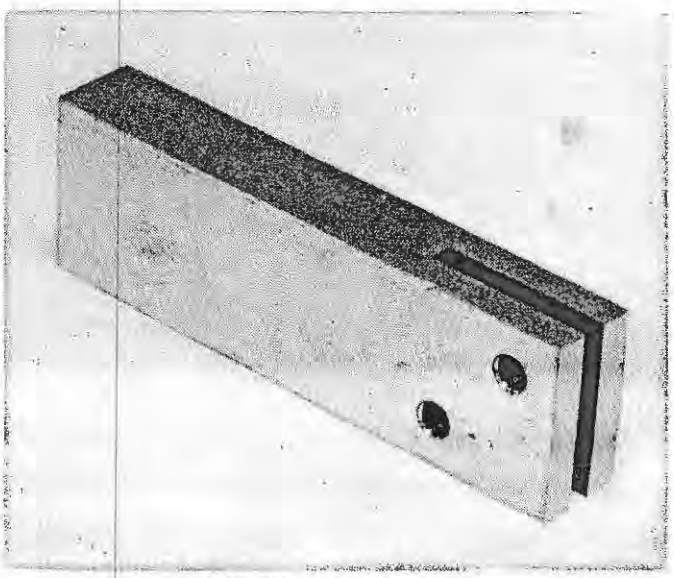


Fig. 2.1 A picture.

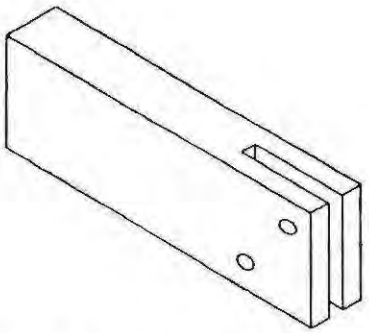


Fig. 2.2 A pictorial drawing.

third-angle orthographic projection has been devised and adopted as the standard method for making drawings in the United States.

Orthographic Projection

In orthographic projection, the edges of a solid that may be perceived from a given viewpoint are drawn on a plane surface without perspective or shade so that a two-dimensional representation is seen by an observer. Because a solid has the three dimensions of height, breadth, and depth, more than one view of an object, therefore, is usually required to give all necessary information about

its shape and size. When one view only is drawn, information about the third dimension must be given by recognized conventions or by means of a note.

Third-angle Orthographic Projection

In third-angle orthographic projection "the six possible principal views"[1] are placed on a drawing in the arrangement illustrated in

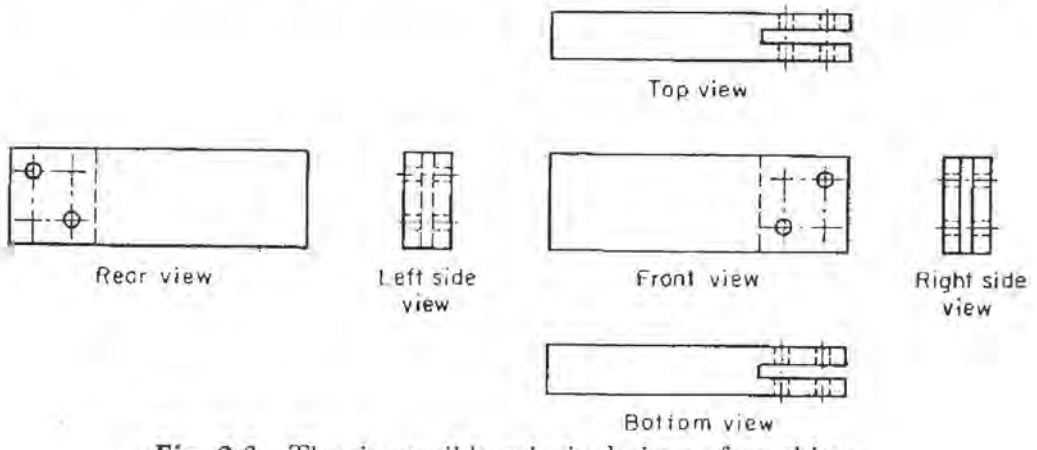


Fig. 2.3 The six possible principal views of an object.

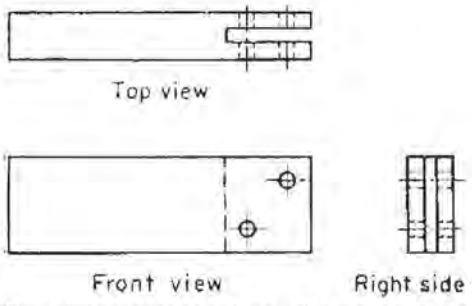


Fig. 2.4 The three views of an object commonly employed.

Fig. 2.3. Most working drawings require three adjacent views, from among these six, to represent an object adequately; and the top, front, and right-side views are usually employed in the arrangement shown by Fig. 2.4. This arrangement is arrived at by visualizing the object as being enclosed in a cubical box having transparent sides, with the sides of the object parallel to the sides of the box as pictured in Fig. 2.5. If the object is viewed from directly in front, the outline

[1] Extracted from "American Standard Drawings and Drafting Room Practice" (ASA Z14.1-1946), with the permission of the publisher, The American Society of Mechanical Engineers, New York.

of its forward surface may be projected along parallel lines and drawn on the front of the box to show its appearance in height and breadth. When viewed from directly above, the top of the object may be drawn on the top of the box to show its breadth and depth. Similarly, the right side of the object may be drawn on the right side of the box to show its height and depth. When the top, front, and

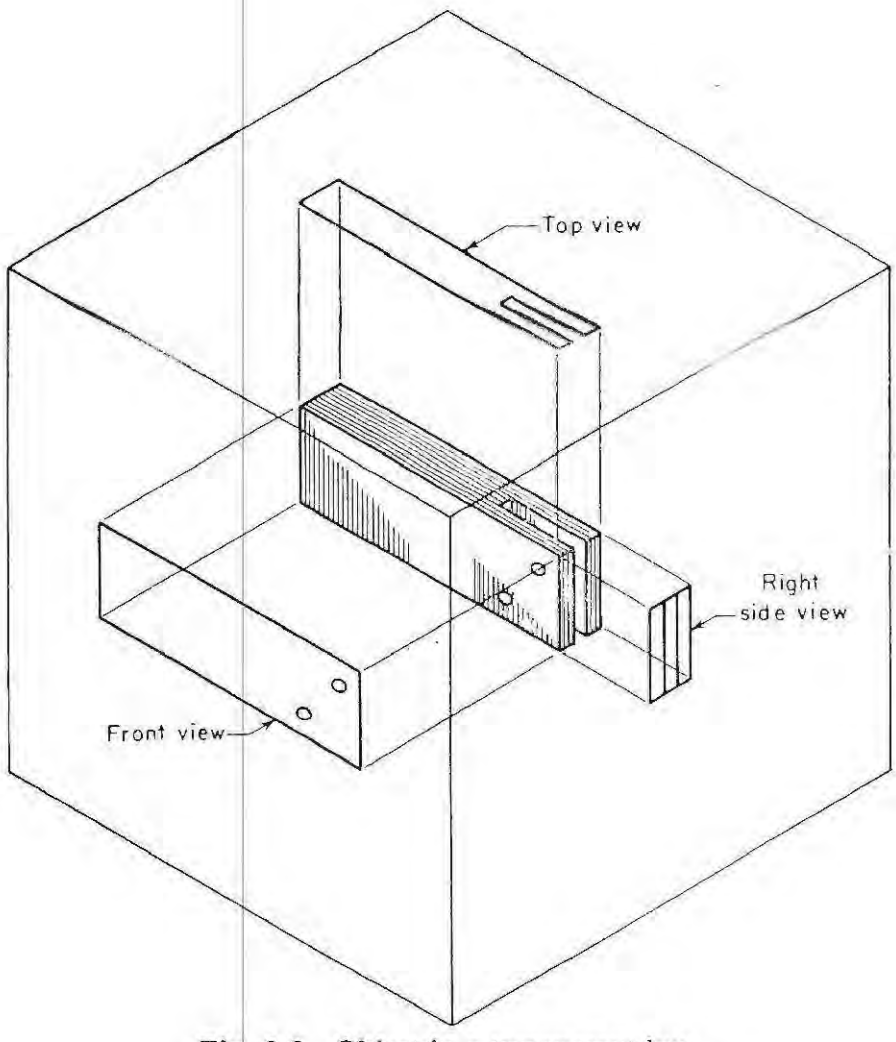


Fig. 2.5 Object in a transparent box.

right sides of the box are revolved into a plane that is perpendicular to the observer's line of sight, they will appear as shown in Fig. 2.6. Now, if the lines that represent the edges of the box are removed, the top, front, and right-side views of the object will be seen as arranged in Fig. 2.4. Finally, dimensions and other information in the form of symbols and notes are added to complete the working drawing shown in Fig. 2.7.

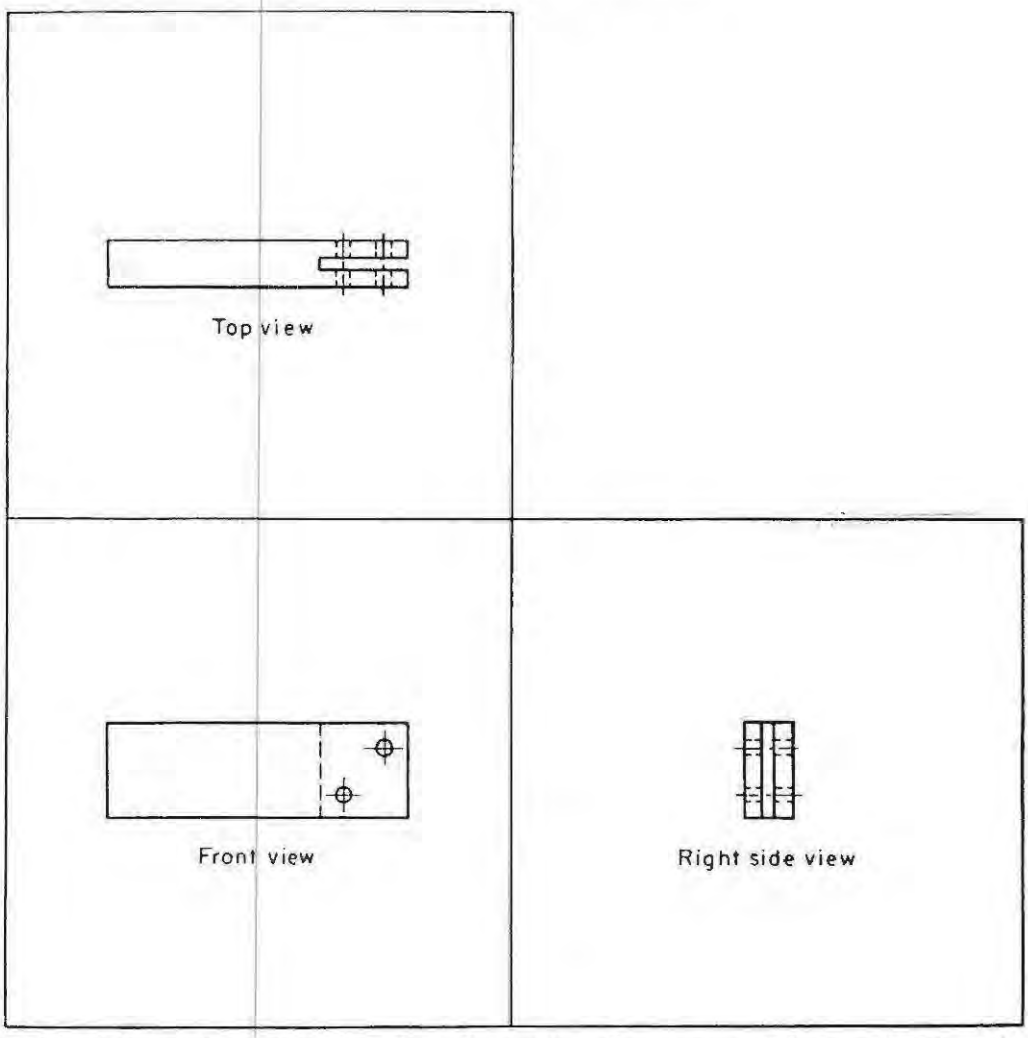


Fig. 2.6 Views of an object projected to sides of transparent box and sides of box revolved into a plane.

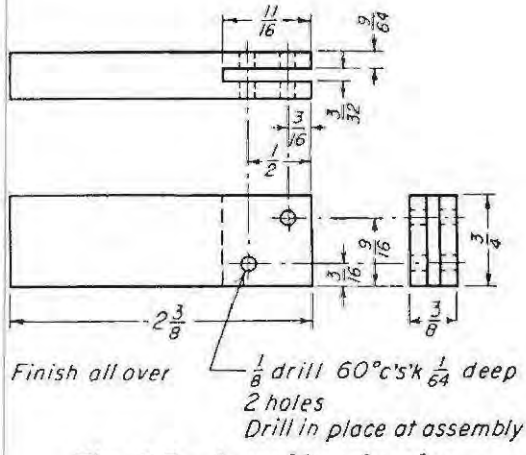


Fig. 2.7 A working drawing.

Width and Character of Lines

Notice that lines which differ in width and continuity are employed in making working drawings. The various types of lines that are used are described and illustrated in Fig. 2.8.

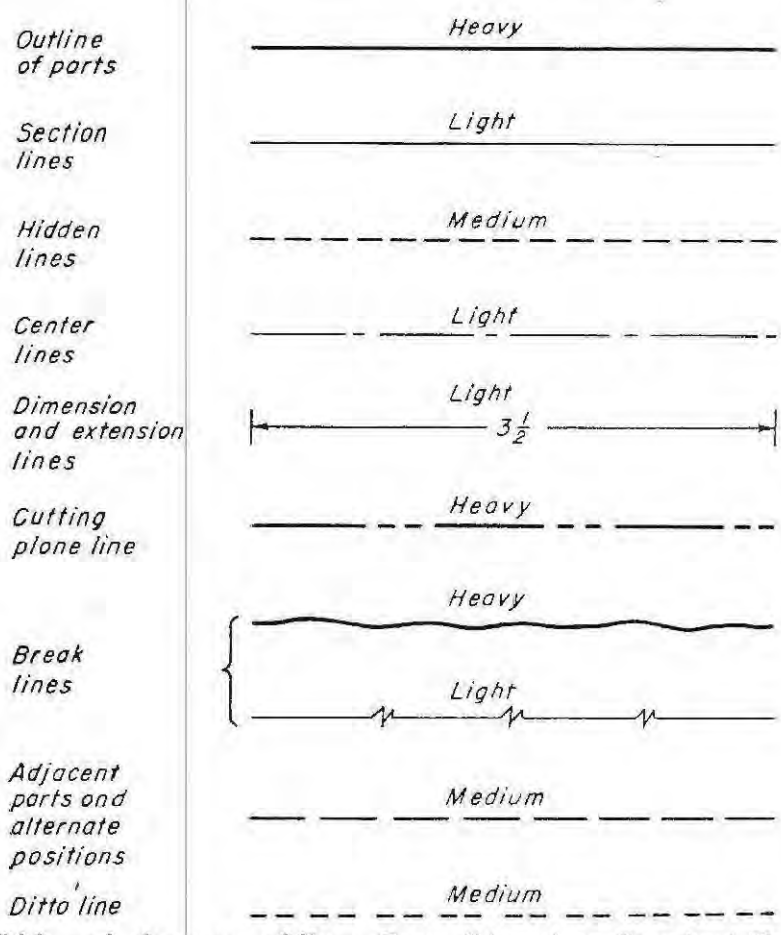


Fig. 2.8 Width and character of lines. From "American Standard Drawings and Drafting Room Practice" (ASA Z14.1-1946). *Courtesy of The American Society of Mechanical Engineers.*

When two views of an object give workmen sufficient information about it, either the top and front views, or the front and right-side views may be shown. Of course, any side of an object may be regarded as the front when a working drawing is made.

Sometimes the diameter of a cylinder, or the thickness of a rectangular bar or plate, may be indicated with a note so that a one-view drawing will give workmen sufficient information about an object.

Auxiliary Views

When an object has a face that is not 90 deg to its other sides, an auxiliary view, illustrated in Fig. 2.9, may be used both to avoid difficult projection and to show true shape and relationship for dimensioning.

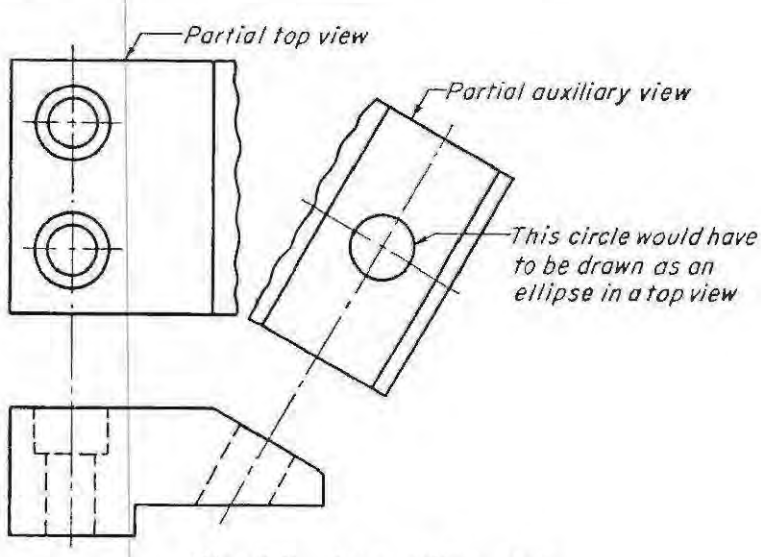


Fig. 2.9 An auxiliary view.

Sectional Drawings

Interior construction of an object, if any, may be shown in one of two ways:

1. Hidden lines may be indicated on outside views by using medium-weight lines composed of short, evenly spaced dashes that are standard for this purpose.

2. When considerable detail involving interior construction must be shown, a sectional drawing is preferable to the use of short-dash lines because it will eliminate errors by avoiding a confusion of lines.

In making a sectional drawing (Fig. 2.10) an imaginary cutting plane is passed through the object, and that part of the object between the observer and the cutting plane is removed. This exposes interior surfaces to view so that lines normally hidden are seen and may be drawn as visible outline. The place where a cutting plane passes through the object is indicated with a cutting-plane line that terminates in direction lines and arrowheads which point away from the observer's station. When more than one cutting plane is

passed through an object, the cutting-plane lines and their corresponding sectional views are marked A-A, B-B, etc., or some other system of identification is used.

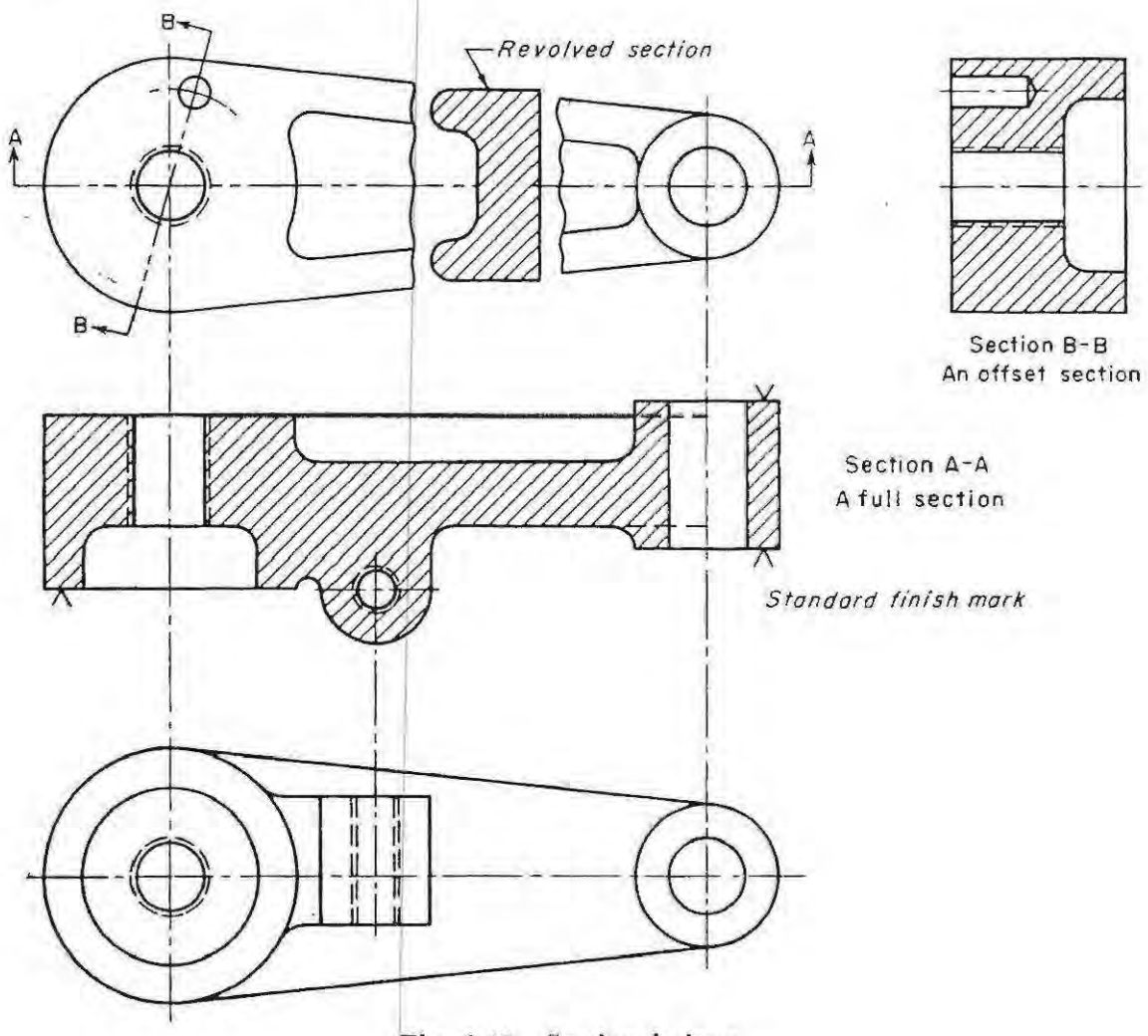


Fig. 2.10 Sectional views.

Crosshatching or section lining is used to indicate the surface on a sectional view that is cut by a cutting plane. Standard section-lining symbols are illustrated in Fig. 2.11.

The symbol for cast iron is often used on drawings, regardless of material; and the material, if other than cast iron, is specified in a note.

Full sections, revolved sections, and offset sections, illustrated in Fig. 2.10, and other variations of this convention may be used to show what is required, in the most effective manner. Whichever

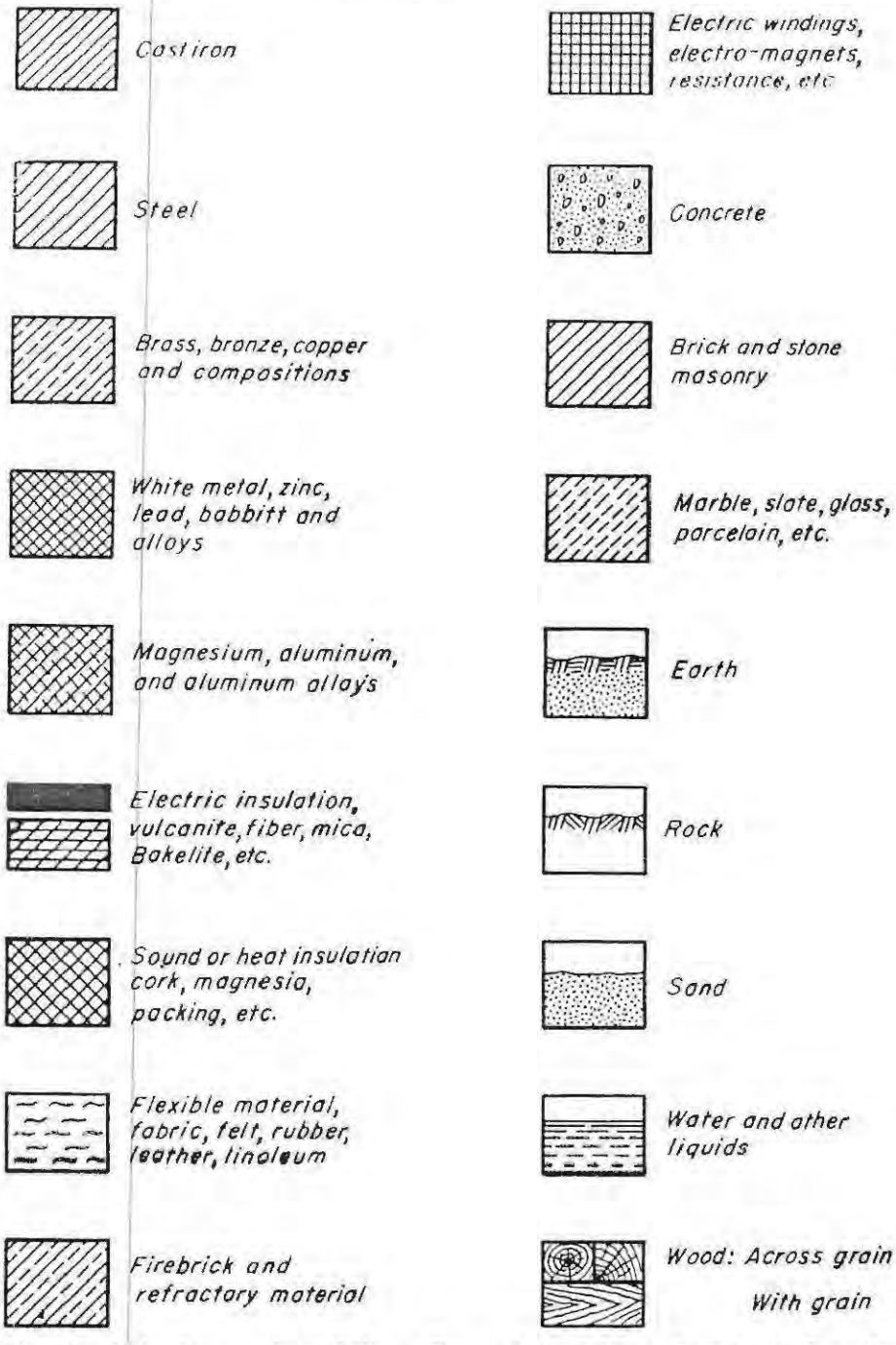


Fig. 2.11 Symbols for section lining. From "American Standard Drawings and Drafting Room Practice" (ASA Z14.1-1946). *Courtesy of The American Society of Mechanical Engineers.*

variation is used, it may be recognized as a sectional view by the characteristic appearance that is produced by the section lining.

Finish Symbols

Surfaces of metal parts that must be finished by a machining operation such as turning, milling, grinding, etc., may be indicated

in several ways. The standard symbol for this purpose is a 60 deg V that has its vertex resting on the line that represents the finished surface. An application of this symbol is illustrated in Fig. 2.10. The older symbol *f* is still employed by some draftsmen for this purpose

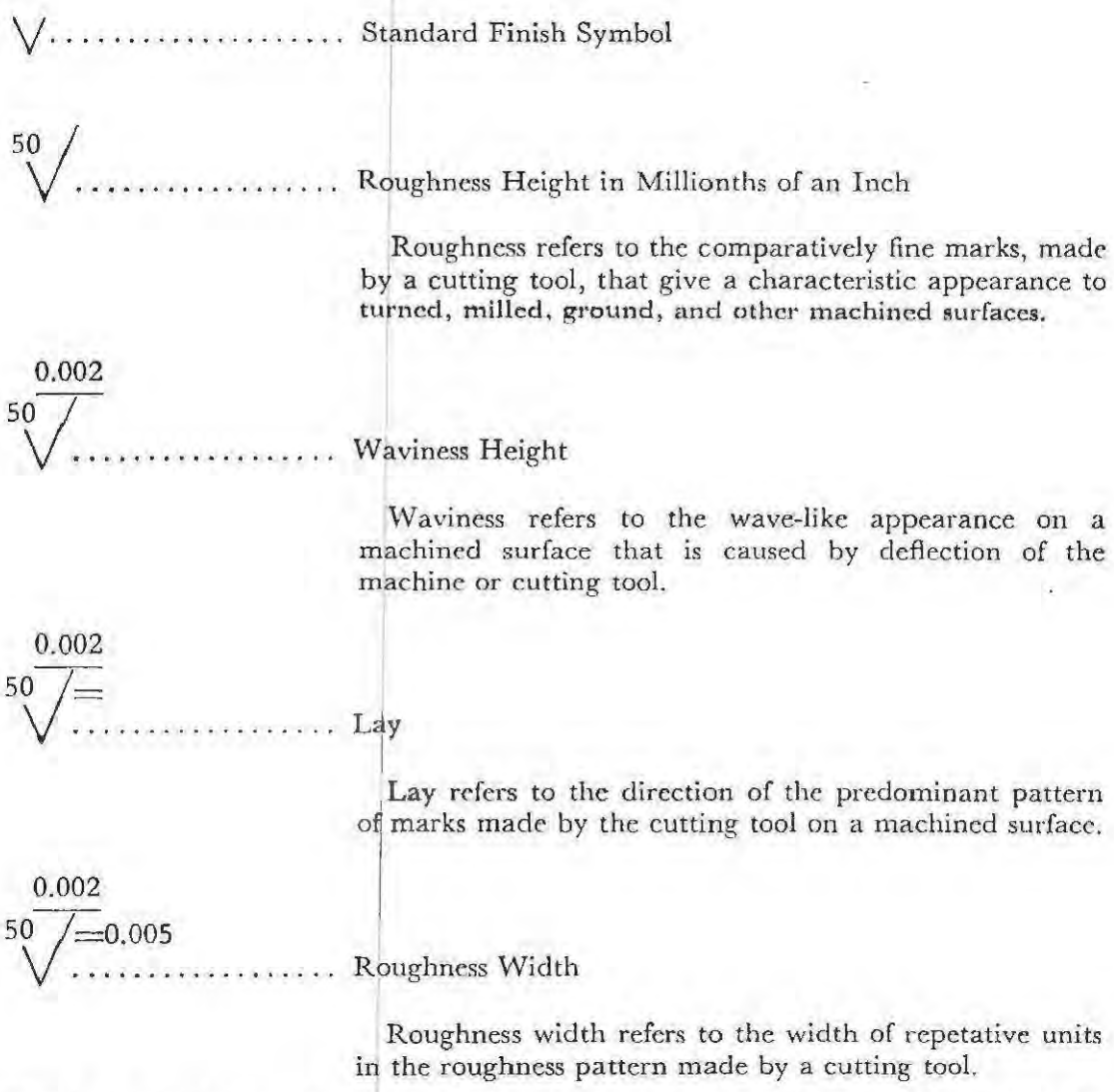

Standard Finish Symbol
50
Roughness Height in Millionths of an Inch
Roughness refers to the comparatively fine marks, made by a cutting tool, that give a characteristic appearance to turned, milled, ground, and other machined surfaces.
0.002
50
Waviness Height
Waviness refers to the wave-like appearance on a machined surface that is caused by deflection of the machine or cutting tool.
0.002
50
Lay
Lay refers to the direction of the predominant pattern of marks made by the cutting tool on a machined surface.
0.002
50
=0.005
Roughness Width
Roughness width refers to the width of repetative units in the roughness pattern made by a cutting tool.

Fig. 2.12 Surface-quality symbols. From "American Standard Drawings and Drafting Room Practice" (ASA Z14.1-1946). *Courtesy of The American Society of Mechanical Engineers.*

and the term "Finish All Over" or its abbreviation FAO may be used in appropriate circumstances.

The quality of a finished surface may be specified by the use of a modified finish symbol; that is, one which has had symbols for surface roughness, waviness, and lay added to it as illustrated in Fig.

2.12. Brief definitions of roughness, waviness, and lay accompany Fig. 2.12. Measurement of surface finish is treated in Chap. 15.

Screw-thread Symbols

Screw threads may be represented on working drawings in a number of ways. Three of the most commonly used conventions are illustrated in Fig. 2.13. Detail *a* in this figure shows a close

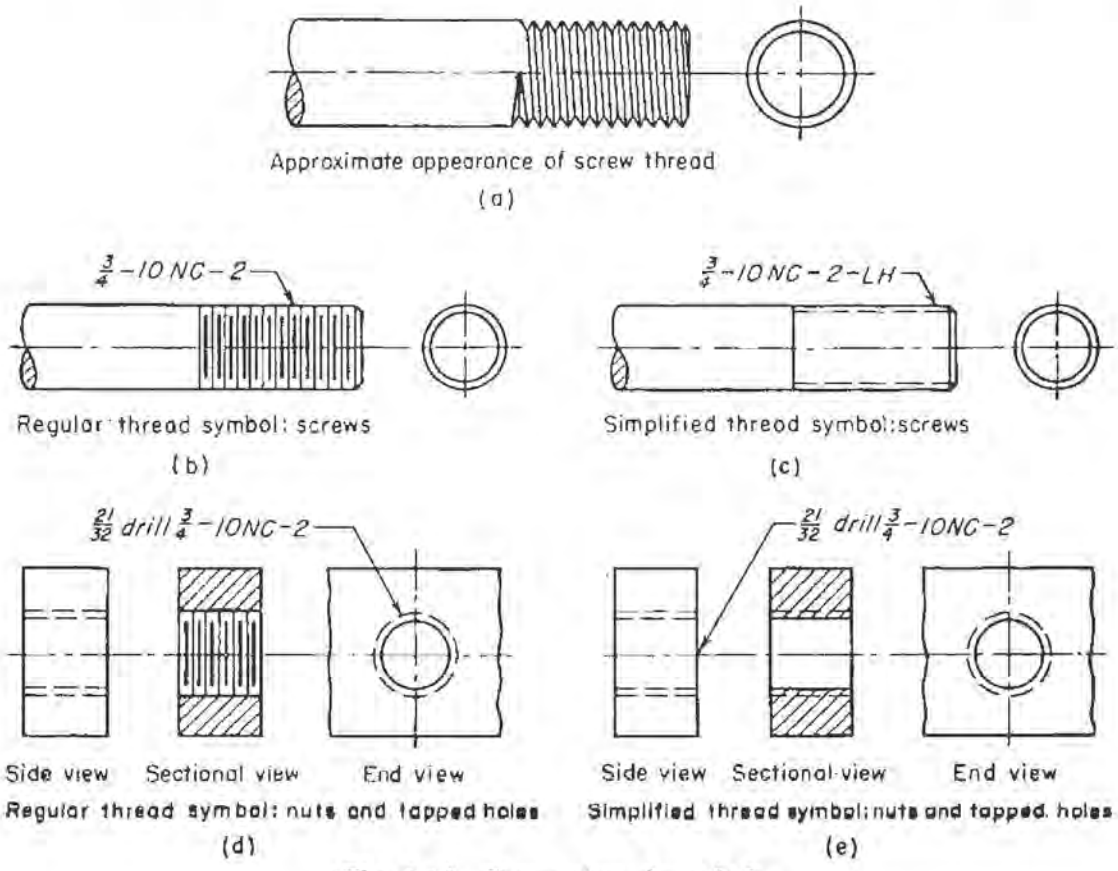


Fig. 2.13 Screw-thread symbols.

approximation to the actual appearance of a screw thread that is used principally for representing large diameter, coarse-pitch screws. Details *b* to *e* inclusive illustrate regular and simplified American Standard thread symbols.

The dimensioning of screw-thread drawings is illustrated in Fig. 2.13 also. The dimension of detail *c*, for example, is ¾ in.-10NC-2 LH. Each position in this dimension has significance as follows:

¾ in.-10NC-2 LH	The dimension.
¾ in.	The major diameter of the screw thread.
10	The number of threads per inch.
NC	The abbreviation for the thread series.
2	The class of fit.
LH	The abbreviation for left-hand thread. The thread is considered to be right-hand when there is no designation in this position.

Miscellaneous Details

Breaks, illustrated in Fig. 2.14, are employed so that long parts may be drawn to a larger scale than would be possible if they were

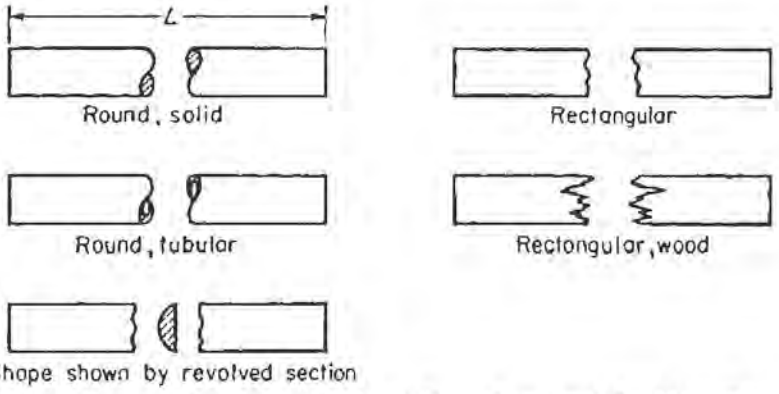


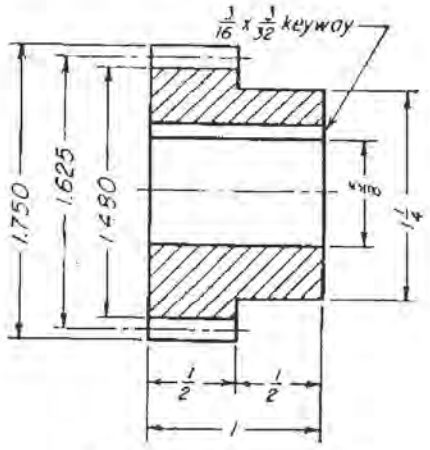
Fig. 2.14 Breaks. From "American Standard Drawings and Drafting Room Practice" (ASA Z14.1-1946). *Courtesy of The American Society of Mechanical Engineers.*

shown in full length in the available space. Either straight or tapered parts of uniform shape in the broken length (L) may be shown in this way.

Gears may be shown by a full sectional view and a tabulation of pertinent information as illustrated in Fig. 2.15.

Representation of knurled surfaces is shown in Fig. 2.16.

Springs may be represented either by drawing an approximation of their appearance or by means of a simple line drawing as illustrated in Fig. 2.17.



Spur gear
16 pitch
26 teeth
$14\frac{1}{2}°$ full-depth involute
0.0982 thickness of tooth
0.0625 addendum
0.1348 whole depth

Fig. 2.15 A spur gear.

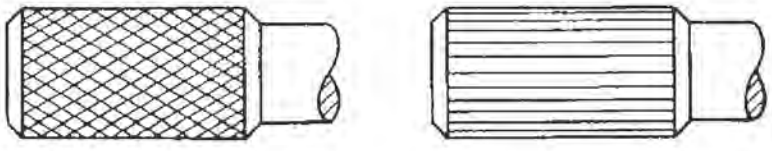


Fig. 2.16 Knurling.

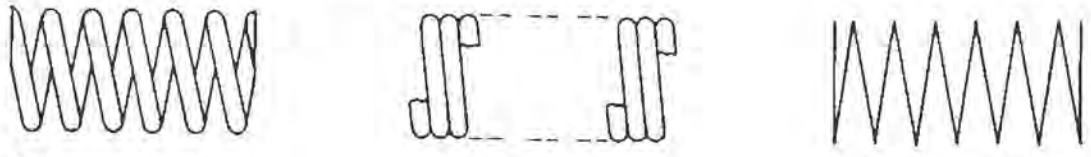


Fig. 2.17 Spring symbols.

Dimensioning

Two systems are employed in dimensioning working drawings: the aligned system and the unidirectional system.

1. In the aligned system, used in Figs. 2.7 and 2.15, all linear dimensions and notes are placed on a drawing so that they may be read from the bottom or right-hand edge of the sheet.

2. In the unidirectional system, used in Fig. 2.18, all dimensions and notes are placed so that they may be read from the bottom of

the sheet. This system is employed principally in the automotive industry.

3. Angular dimensions, in both systems, are preferably placed so that they may be read from the bottom of the sheet.

When dimensions on a machine drawing are in inches, it is customary to omit the inch symbol.

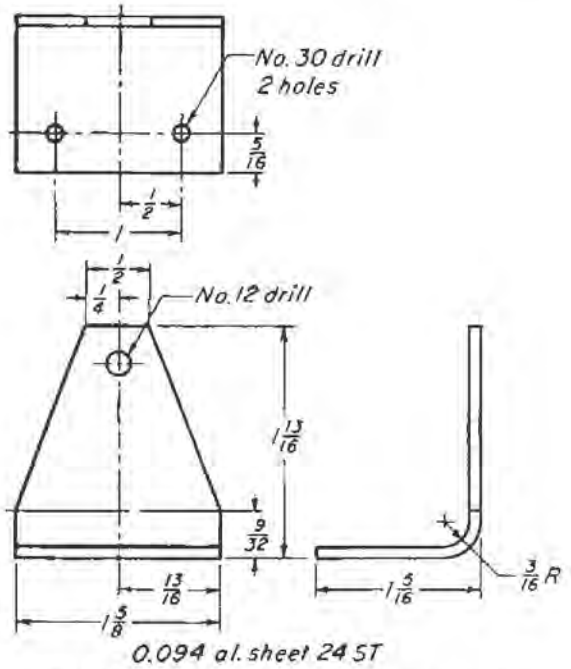


Fig. 2.18 Unidirectional dimensioning.

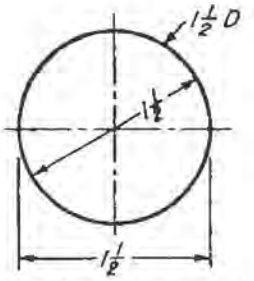


Fig. 2.19 Dimensioning circles.

Fig. 2.20 Dimensioning radii.

Practice in specifying feet and inches differ in various industries:

1. All dimensions are expressed in inches.
2. All dimensions to and including 72 in. are expressed in inches, and above that in feet and inches.
3. All dimensions are expressed in feet and inches.

Circles may be dimensioned in several ways. Three methods commonly used are illustrated in Fig. 2.19. Methods of dimension-

ing radii are illustrated in Fig. 2.20. Figure 2.21 illustrates ways of representing and dimensioning drilled holes and holes that have been modified by countersinking, counterboring, etc. Some of the drawings are dimensioned on two views to show alternate methods which may be employed.

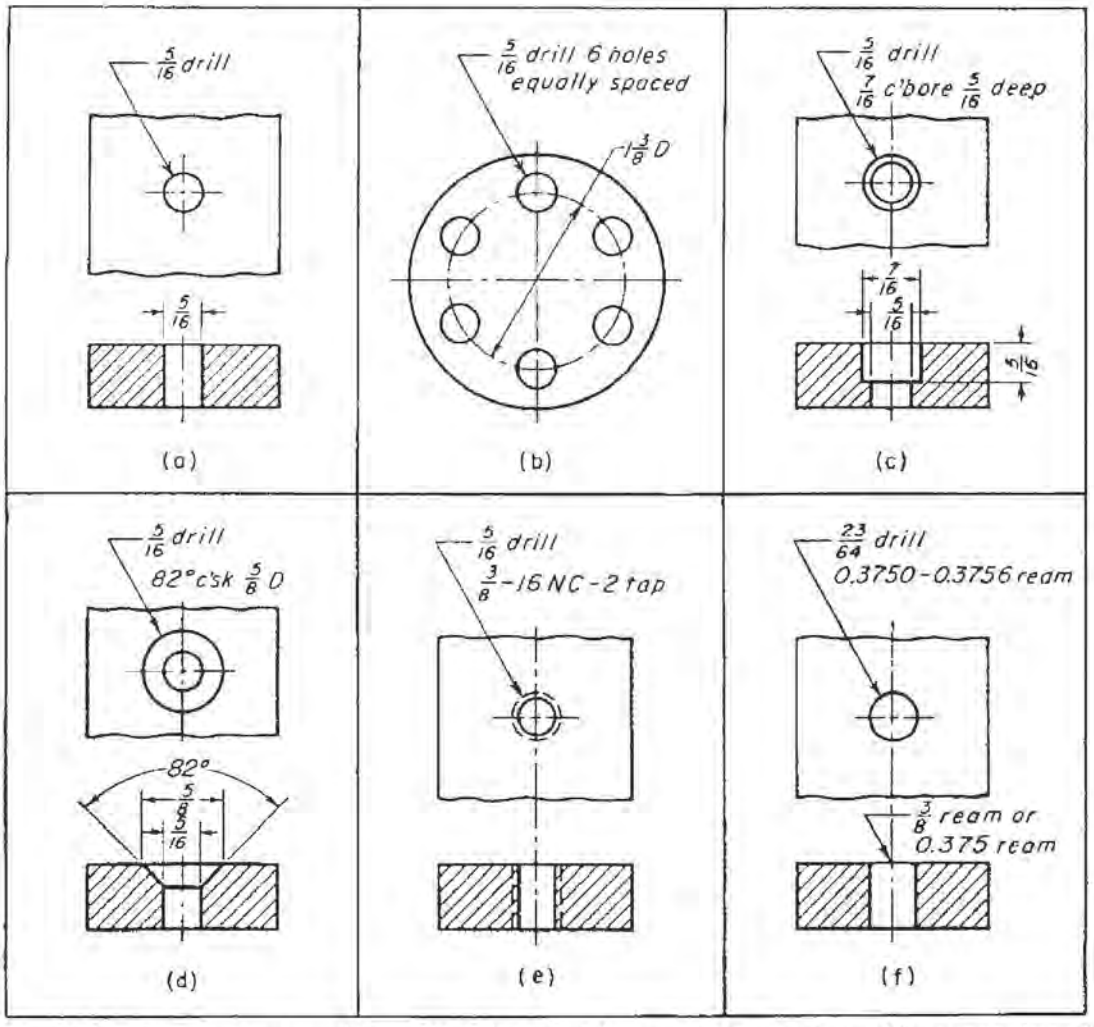


Fig. 2.21 Dimensioning (*a*) drilled holes, (*b*) a repeated detail, (*c*) counterbored holes, (*d*) countersunk holes, (*e*) tapped holes, (*f*) reamed holes.

Dimensioning Limits

It is known that unavoidable variation in a material and manufacturing process will result in a dimensional variation in the parts which are produced by that process. This is recognized by permitting a controlled variation in the size of a manufactured part. This permissable variation in size is called *tolerance*, and the dimensions between which variation is permitted are called *limits*. Several

methods of dimensioning a working drawing to show tolerance or limits are illustrated in Fig. 2.22.

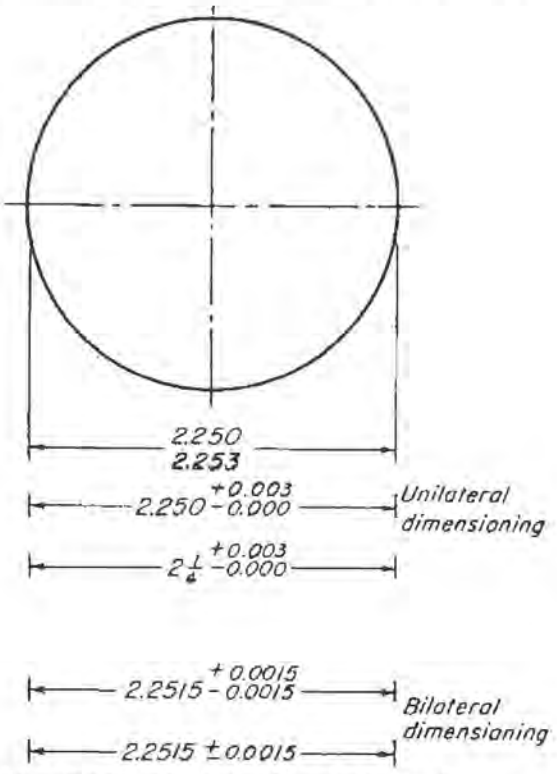


Fig. 2.22 Unilateral and bilateral systems of tolerance or limit dimensioning.

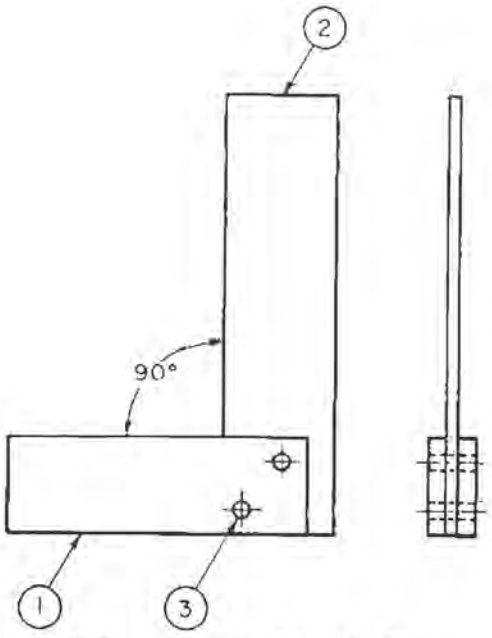


Fig. 2.23 An assembly drawing.

Assembly and Detail Drawings

There are two general types of working drawings: assembly drawings and detail drawings.

An *assembly drawing* (Fig. 2.23) is one that shows the several parts of a subassembly, or a final assembly, in their proper relationship to each other. Each part on an assembly drawing is identified by a letter, number, or symbol; and this identification is used when referring to the various parts in the bill of material, detail drawings, and all other documents that are employed in their production, sale, and use. Usually, over-all dimensions that assist in showing relationships between components are the only ones that appear on an assembly drawing.

A *detail drawing*, illustrated in Fig. 2.24, is a drawing of an individual part of an assembly or subassembly. It gives complete information about its size, shape, material, finish, and other particu-

lars by means of conventional representation, notes, and symbols. With this information, workmen may produce the article to the specifications established by the engineering department.

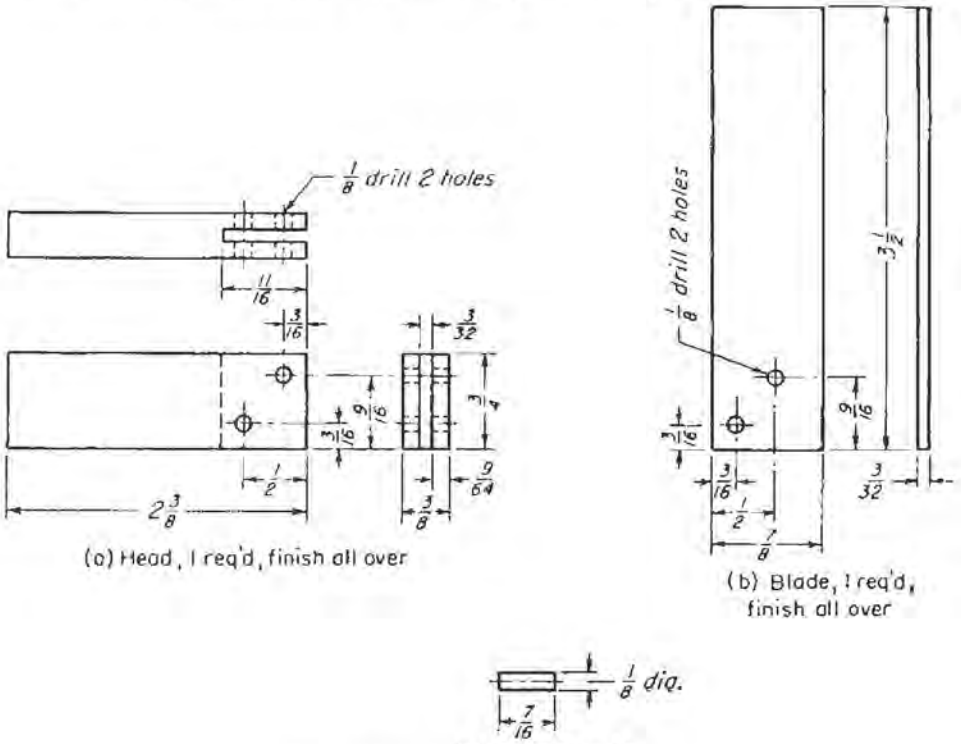


Fig. 2.24 A detail drawing.

Bill of Material, Title, Notes, and Revisions

A *bill of material* (Fig. 2.25) is an itemized statement of all parts that are required to construct one unit of an assembly. It gives

BILL OF MATERIAL

Part No.	Part name	Material	Required	Remarks
1	Head	AISI C 1020	1	Drill with part 2 in place
2	Blade	AISI C1020	1	
3	Rivet	AISI C1020	2	

Fig. 2.25 A bill of material.

information about the kind of material required to make each part, the quantity to be produced, and special directions required for its production or purchase. The bill of material may be placed on the assembly drawing, or it may consist of a separate document.

A *title* (Fig. 2.26) is usually located at the lower right-hand corner of a working drawing. It should contain the name of the manu-

	Notes	Scale	COMPANY NAME
		Drawn by	
		Traced by	PART NAME
2.		Checked by	
1.		Approved by	DRAWING NUMBER
Revisions		Date	

Fig. 2.26 A title block.

facturing company, an identifying number, the name of the object shown on the drawing, a statement of the scale to which the drawing is made, the date when the drawing was completed, and signatures or initials of those who made, traced, checked, and approved the drawing. General notes and a change record are often included in a block with the title.

General notes are notes that would have to be repeated a number of times if they were not recorded in this form.

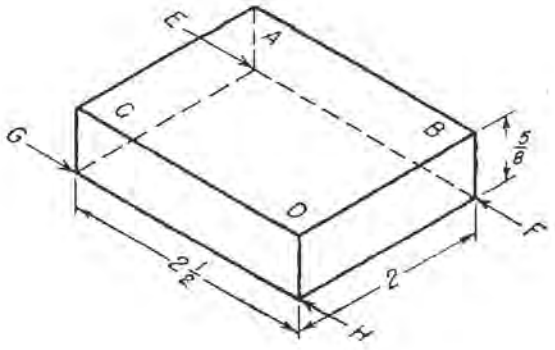
A *change record* is a statement of revisions or alterations to the drawing, and dates when they were made.

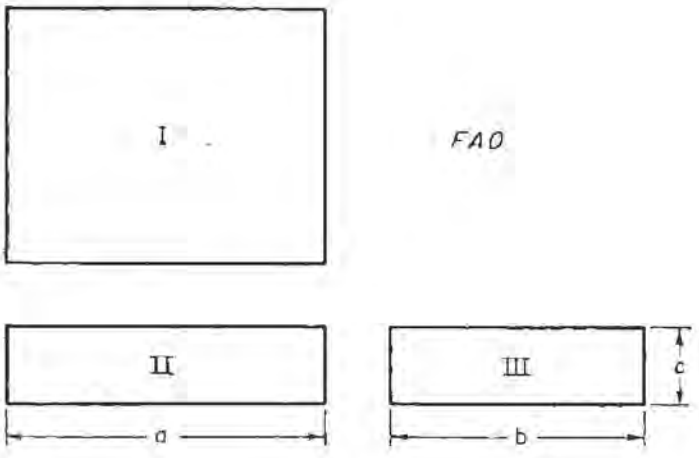
Most of the information that an inspector requires for doing his job can be obtained by studying the details of working drawings. In some instances, however, he will have to obtain information from a written specification or by examining a sample.

BLUEPRINT READING PROBLEMS

Problem 1

1. What is the name of the view marked:
   I. _____
   II. _____
   III. _____
2. How many views are needed to represent this object?
   _____
3. What dimension should be inserted at:
   a. _____
   b. _____
   c. _____
4. What lines (as *AB*, etc.) bound the view marked:
   I. _____
   II. _____
   III. _____
5. What designation is applied to lines listed below:
   AB. _____
   EF. _____
   Lines terminating in arrowheads. _____
   Lines at which arrowheads terminate. _____
   Line from *F* to the die blank. _____
6. The dimension 2, for example, represents a measurement in what kind of units? _____
7. What is the name of this part? _____
8. How many are to be made? _____
9. Of what material is it to be made? _____
10. What does the symbol FAO mean? _____





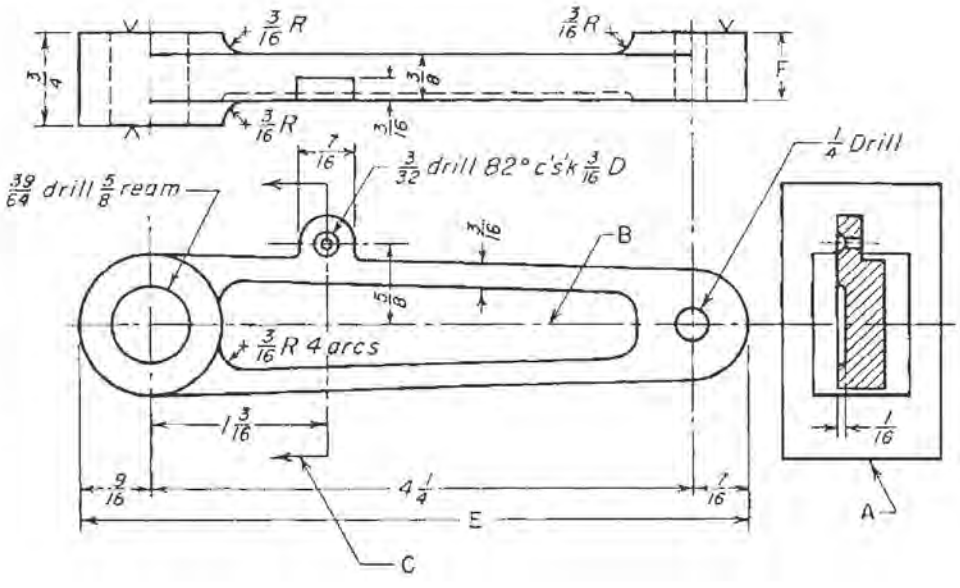
Blueprint Reading	Part Name *Die blank*
Problem *1*	Part No. *6* Required *1*
	Material *AISI C1095* Scale *Full*

Problem 2

1. What kind of drawing is that in the box marked *A*?

2. What name is given to the diagonal lines in this drawing?

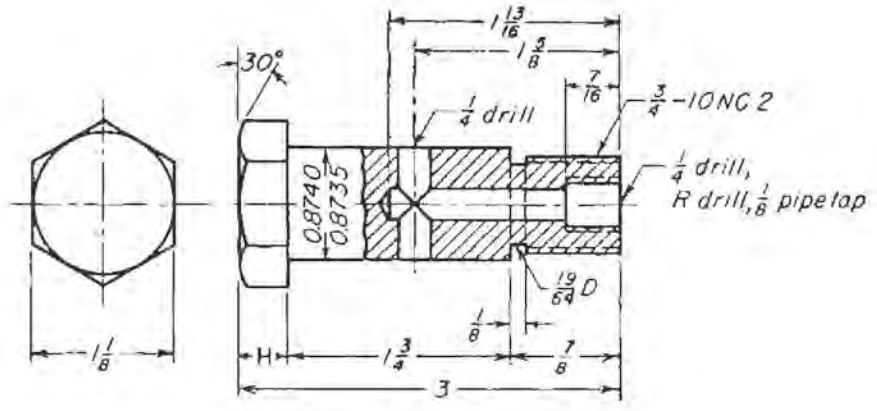
3. What is the meaning of the following symbols:
   The letter *R*? _____
   The letter *D*? _____
   The symbol V? _____
4. What kind of line is indicated at *B*? _____
5. What kind of line is indicated at *C*? _____
6. What kind of line extends from the dimension ¼ drill, for example, to the hole to which it applies? _____
7. What is the over-all dimension *E*? _____
8. What kind of drawing is this? _____
9. What is the material of which this part is made? _____



Blueprint Reading	Part Name *Tension arm*
Problem *2*	Part No *12* Required *1*
	Material *CI* Scale *Full*

Problem 3

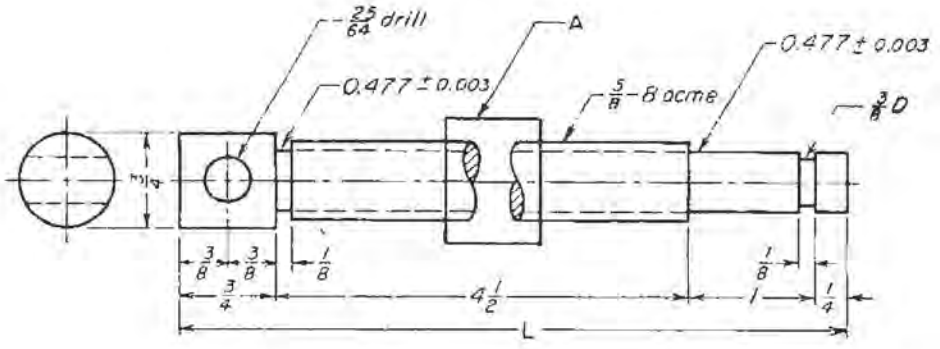
1. In the dimension $^{3}/_{4}$ in.-10NC-2, what does each of its parts mean?
   $^{3}/_{4}$ in. _____
   10 _____
   NC _____
   2 _____
2. What is the height *H* of the head? _____
3. Two dimensions are given for the body diameter:
   a. What are these dimensions called? _____
   b. What is the difference in these dimensions called? _____
4. What is the full diameter depth of the $^{1}/_{4}$ longitudinal hole? _____
5. What is the distance from the end of the stud to the center line of the transverse hole? _____
6. What is the depth of the tapped hole? _____
7. How many of these components are required for a unit assembly of the machine of which they are a part? _____



Blueprint Reading	Part Name *Intermediate gear stud*
Problem *3*	Part No. *12* Required *3*
	Material *AISI C1040* Scale *Full*

Problem 4

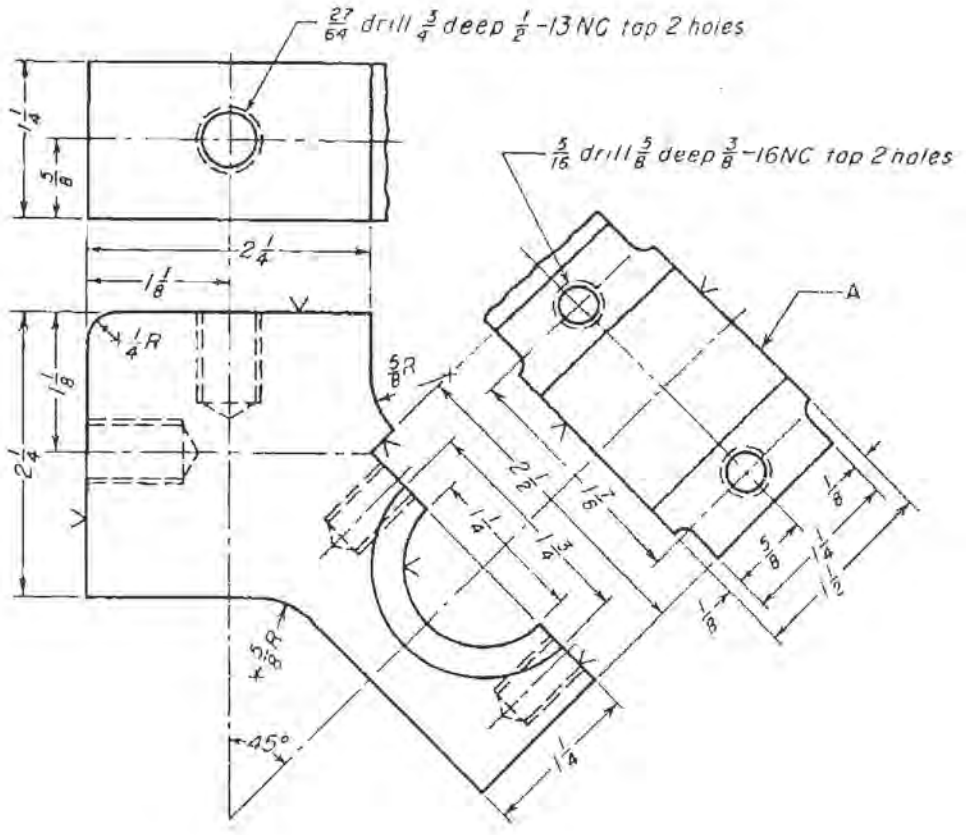
1. What is the conventional representation enclosed in the box *A* called? _____
2. What does the foregoing representation signify? _____
3. Why are conventions of this kind used in making drawings? _____
4. What is the over-all length *L* of this piece? _____
5. Rewrite the bilateral dimension 0.477 ± 0.003 in unilateral form. _____
6. How many threads per inch does this screw have? _____
7. What is the nominal major diameter of this screw? _____



Blueprint Reading	Part Name *Vise screw*
Problem *4*	Part No *3* Required *1*
	Material *AISI C1115* Scale *Full*

Problem 5

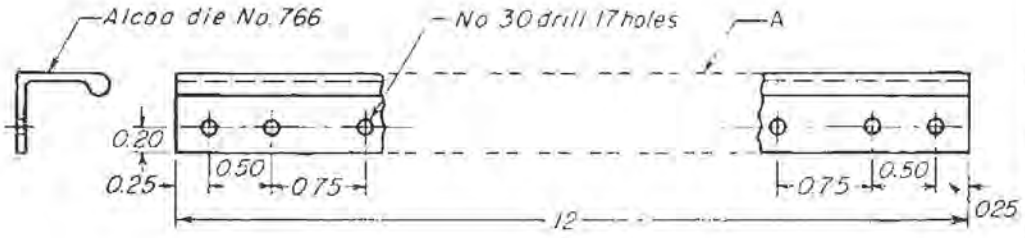
1. What kind of view is shown at *A* in this problem? _____
2. Explain briefly why the view at *A* is preferable to a right-side view? _____
3. What is the diameter of the $^{3}/_{8}$ in. -16NC tap drill? _____
4. How many holes are to be tapped $^{3}/_{8}$ in.-16NC? _____
5. How deep are they to be drilled and tapped? _____
6. What is the center distance between them? _____
7. Sketch an end view of a tapped hole.



Blueprint Reading	Part Name *Front bearing*
Problem 5	Part No. *1.b 5* Required *2*
	Material *CI* Scale *Full*

Problem 6

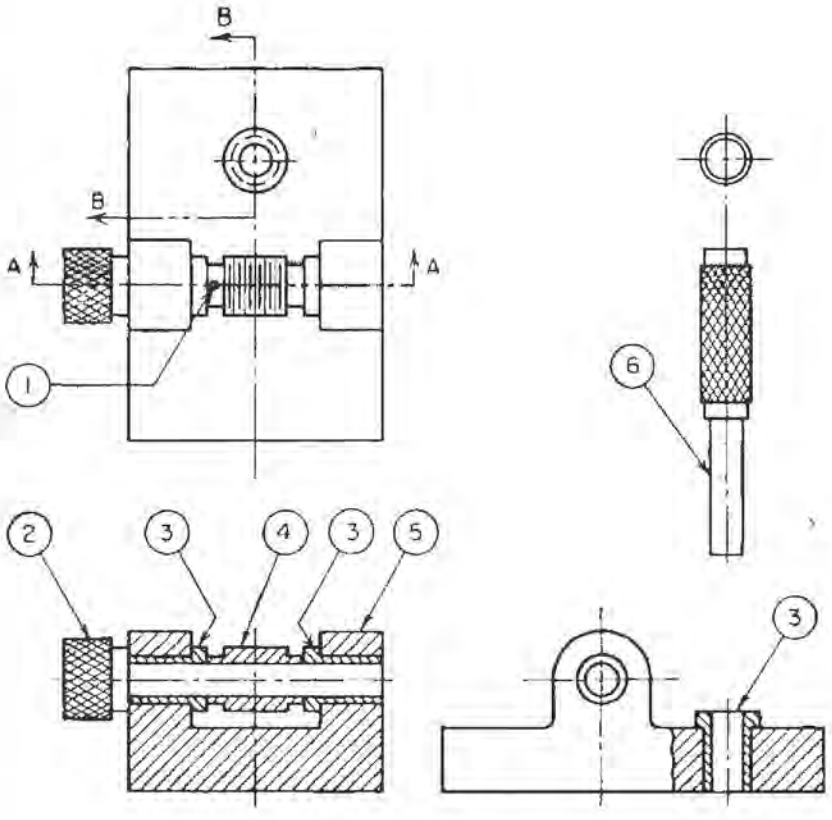
1. What kind of line is shown at *A* in this problem?
2. What does this kind of line indicate?
3. How many No. 30 holes are to be drilled?
4. What is the center distance between holes not shown in the drawing?
5. How many stiffeners are required?
6. Height and depth are not dimensioned on this drawing. What takes their place?



Blueprint Reading	Part Name *Skin stiffener*
Problem *6*	Part No. *-2* Required *4*
	Material *24 ST Al* Scale *Full*

Problem 7

1. What kind of drawing is this? _____
2. Are any parts of this gage alike? If so, what number, and how many are required? _____
3. What parts of this gage must be made? _____
4. What part of this gage is a purchased item? _____
5. What part of this gage is a production item? _____
6. What title belongs at *A*, page 2, of this problem? _____
7. What is the block at the bottom of page 1 of this problem called? _____



Section A-A Section B-B

Blueprint Reading	Part Name *Gage*
Problem *7 Page 1*	Part No. *Dwg 26-27* Required *1*
	Material Scale *Full*

A

Item No.	Part No.	Part name	Material	Req'd	Remarks
	1	5/10 x 3/8 taper pin		1	Pur.
	2	Spindle, worm	AISI C1020	1	Make
	3	Bushing	AISI C1090	3	Make Heat treat
	4	Worm		1	Part No. DW 26
	5	Body	CI	1	Make
	6	Spindle, worm gear	AISI C1090	1	Make Heat treat

Blueprint Reading	Part Name
Problem 7 Page 2	Part No. Required
	Material Scale

3

STANDARDS OF LENGTH

Most industrial inspection consists of determining the chemical analysis and physical properties of materials and of verifying the dimensions of manufactured products by comparing them with standards of length. This manual will deal, almost entirely, with the tools and methods that are used to measure lengths.

Standards of Length

Two standards of length are in common use in the United States: the yard, employed in manufacturing operations, and the meter, used in scientific work.

Standard yard

The yard that is used in the United States is derived from the British Imperial standard yard which was adopted as the legal standard of length by the British Parliament in 1855. This standard consists of a bronze bar, called Bronze No. 1, that has gold plugs inserted in transverse holes in the ends of the bar so that surfaces of the plugs lie on the central plane of the bar. Each plug has three transverse and two longitudinal lines on its end surface. The standard yard is, by definition, the distance between the middle transverse lines, measured between the longitudinal lines at the temperature of 62°F. The British government presented two copies

of the standard yard to the United States in 1856. One of these copies, Bronze No. 11, is a duplicate of the original standard. It measures one yard at the temperature of 62.25°F, and has been accepted as the standard yard in the United States since its presentation to this country. The other copy is a bar of low-moor iron, No. 57. It measures one yard at the temperature of 62.58°F.

Standard meter

The meter was established as the result of work that was done by a French commission which was appointed in 1790 to provide a national standard of length for that country. The commission decided that the standard should be 1/10,000,000 of the quarter meridian passing through Paris. After this length was determined, a platinum standard was made with end surfaces that defined the meter.

Congress passed a law to *permit* the use of the meter in the United States and, in 1866, defined the yard as 3,600/3,937 of the meter. The meter is the only measure of length legalized here, even to this extent.

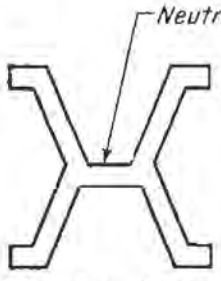


Fig. 3.1 Shape of bar for international standards of length.

The International Bureau of Weights and Measures, with its location in Paris, was established by treaty among interested nations in 1875. This bureau prepared a new prototype meter and made thirty copies of it because the 1790 meter was not satisfactory. The new standard was made of a platinum-iridium alloy, and the bar was shaped in cross section as shown in Fig. 3.1. Three fine transverse lines are engraved on the neutral plane at each end of the bar. The longitudinal distance between the middle lines, measured at 0°C, is one meter by definition. The United States participated in establishing and maintaining this bureau, and it received two copies of the Prototype Meter, Nos. 21 and 27.

The International Prototype Meter was declared to be the

fundamental unit of length in the United States by formal order of the Secretary of the Treasury in 1893.

Copies of the standards of length that have been described are preserved in the National Bureau of Standards. Meter No. 27 is the master standard, and it is sealed in a metal case and kept in a fireproof vault for safety.

Measuring with Light Waves

In 1894, the physicist Michelson determined, by the use of his interferometer, the length of the Prototype Meter to be 1,553,163.5 wavelengths of the red line in the spectrum of cadmium. This was an important development in the science of measurement because it provided a natural, invariable standard whereby the meter may be reproduced at any time should it become lost. On the basis of later measurements, the International Conference of Weights and Measures provisionally adopted the relation of 1,553,163.13 wavelengths equal one meter.

In 1948, the National Bureau of Standards proposed that wavelengths of the green line in the spectrum of mercury 198 be used to define the meter. Mercury with an atomic weight of 198 is obtained by transmuting gold in a nuclear-reaction pile. One wavelength of green light from this source measures nearly 21 millionths of an inch; and 1,831,249.21 wavelengths equal one meter.[1]

From foregoing statements, it is evident that legal standards of length are metal bars with lines on them but that the most precise measurements of length are made with light waves.

Divisions of the Yard

For measurements in manufacturing and inspection operations, the yard is divided into feet and inches, and inches are divided into common and decimal fractions. The common fractions usually employed are halves, quarters, eighths, sixteenths, thirty-seconds,

[1] National Bureau of Standards, "Technical News Bulletin," Vol. 35, No. 3, March, 1951.

and sixty-fourths of an inch. The decimal divisions of tenths and hundredths of an inch are used for nonprecision measurements, of thousandths and ten-thousandths of an inch for precision measurements, and of hundred-thousandths and millionths of an inch for making and inspecting precision gages.

An inspector should be familiar with the decimal equivalents of eighths, sixteenths, thirty-seconds, and sixty-fourths of an inch given in Table 1; he should be able to add and subtract common fractions; and he should be able to convert common fractions into their decimal equivalents.

Addition of Common Fractions

Rule: (*a*) If it is necessary, reduce the fractions so that they will have a least common denominator. To do this, find the least common multiple of the denominators. (*b*) Add the numerators and write their sum over the least common denominator. (*c*) If this makes an improper fraction, reduce it to a whole or mixed number.

In many cases, the least common denominator may be determined by scanning the problem, and the fractions may be reduced to their required forms by mental calculations.

Problem: Add $^{11}/_{16}$, $^{13}/_{32}$, $^{3}/_{8}$, $^{9}/_{32}$, and $^{1}/_{2}$.

Solution: The fractions must be reduced to have a least common denominator. Therefore, find the least common multiple of their denominators as the first step.

(*a*) 2)16, 32, 8, 2
4) 8, 16, 4, 1
2) 2, 4, 1
1, 2

$2 \times 4 \times 2 \times 2 = 32$

$^{11}/_{16} \times {}^{32}/_{32} = {}^{22}/_{32}$

$^{3}/_{8} \times {}^{32}/_{32} = {}^{12}/_{32}$

$^{1}/_{2} \times {}^{32}/_{32} = {}^{16}/_{32}$

(*b*) $^{22}/_{32} + {}^{13}/_{32} + {}^{12}/_{32} + {}^{9}/_{32} + {}^{16}/_{32} = {}^{72}/_{32}$

(*c*) $^{72}/_{32} = 2{}^{8}/_{32} = 2\frac{1}{4}$ *Ans.*

Subtraction of Common Fractions

Rule: (*a*) If it is necessary, reduce the fractions so that they will have a common denominator. To do this, find the least common multiple of the denominators. (*b*) Find the difference in the numerators and write it over the common denominator. If mixed numbers are involved, subtract the fractions then the whole numbers.

Problem: Subtract $2\frac{21}{32}$ from $4\frac{1}{4}$.

Solution: The least common denominator is determined to be 32 by scanning the problem.

(*a*) $4\frac{1}{4} = 4\frac{8}{32}$

$4\frac{8}{32} = 3\frac{40}{32}$

(*b*) $3\frac{40}{32} - 2\frac{21}{32} = 1\frac{19}{32}$ *Ans.*

Finding the Decimal Equivalent of a Common Fraction

Rule: (*a*) Write a decimal point and zeros after the numerator of the fraction. The number of zeros required will be determined as work progresses. (*b*) Divide the numerator by the denominator. (*c*) Place a decimal point in the quotient to make as many decimal places as there are added zeros.

Problem: Find the decimal equivalent of $\frac{1}{40}$.

Solution: 40)1.000(0.025 *Ans.*

80

200

200

Divisions of the Meter

The inspector may find it necessary to employ metric units of length in his work, and to convert English measurements into their metric equivalents or vice versa. The metric units of length that are commonly used in manufacturing are:

10 millimeters (mm) = 1 centimeter (cm)

10 centimeters = 1 decimeter (dm)

10 decimeters = 1 meter (m)

Conversion of metric units into their English equivalents is based on the following relationships:

1 millimeter = 0.0394 in.
1 centimeter = 0.3937 in.
1 decimeter = 3.9370 in.
1 meter = 39.37 in. = 3,937/3,600 yards

Conversion of English units into their metric equivalents is based on the following relationships:

1 in. = 25.4 millimeters
1 yard = 3,600/3,937 meters = 0.9144 meters

The value 1 in. = 25.4 mm has been approved for use in manufacturing by the American Standards Association, by Great Britain, and by continental European countries.

Although conversion units have been given in the foregoing paragraphs, the inspector who must convert measurements from one system of units to the other is advised to use handbook tables for this purpose.[1,2]

International Temperature

The international standard temperature for linear measurement is 68°F, or 20°C. This is so near the working temperature in industrial plants that the effect of temperature may be neglected in ordinary work. The expansion and contraction of metal due to temperature changes is important, however, in gage making and gage checking. Gage laboratories, therefore, are equipped with temperature and humidity control. Humidity control is included as a part of such installations to assist in making comfortable working conditions and to help prevent rusting of fine tools.

[1] Fred H. Colvin and Frank A. Stanley, "American Machinists' Handbook," 8th ed., McGraw-Hill Book Company, Inc., New York, 1950.

[2] Eric Oberg and F. D. Jones, "Machinery's Handbook," 13th ed., Industrial Press, New York, 1946.

QUESTIONS

1. What standard of length is used in the United States for (*a*) industrial measurements and (*b*) scientific measurements?

2. What common fractions of an inch are usually employed in industrial measurements?

3. What is the international standard temperature for linear measurements?

4

METAL FITS

An inspector should be familiar with the concepts and terms that are used to specify the condition of clearance or interference that exists between mating parts of a mechanism when they are assembled. This condition of clearance or interference is called a *fit*.

Tolerance Dimensioning

It is customary to dimension the two elements of a fit with tolerance or limits. That is, two dimensions which specify maximum and minimum sizes for each element are placed on working drawings of mating parts as shown in Fig. 4.1. This practice is followed for two reasons. First, any attempt to work to an absolute dimension slows the rate of production and adds to its cost; second, it is impossible to work to an absolute dimension because unavoidable variations in a manufacturing process and in successive units of material prevent it. As an alternative, work is permitted to vary between maximum and minimum sizes or limits.

Definitions

The terms that are used in tolerance or limit dimensioning are illustrated in Fig. 4.1 and Fig. 4.2, and they are defined in the following statements:

Nominal size: Nominal size is an indication of the approximate size of a part or parts. The nominal size of the parts in Fig. 4.1 is $2\frac{1}{4}$ in.

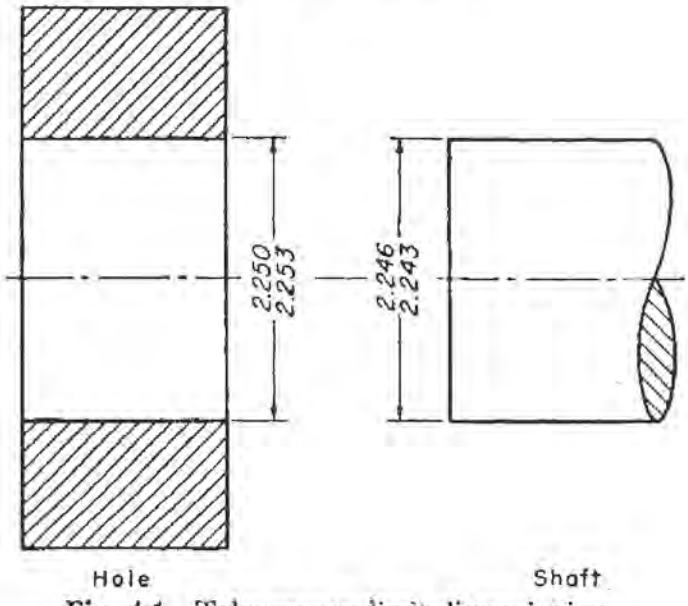


Fig. 4.1 Tolerance or limit dimensioning.

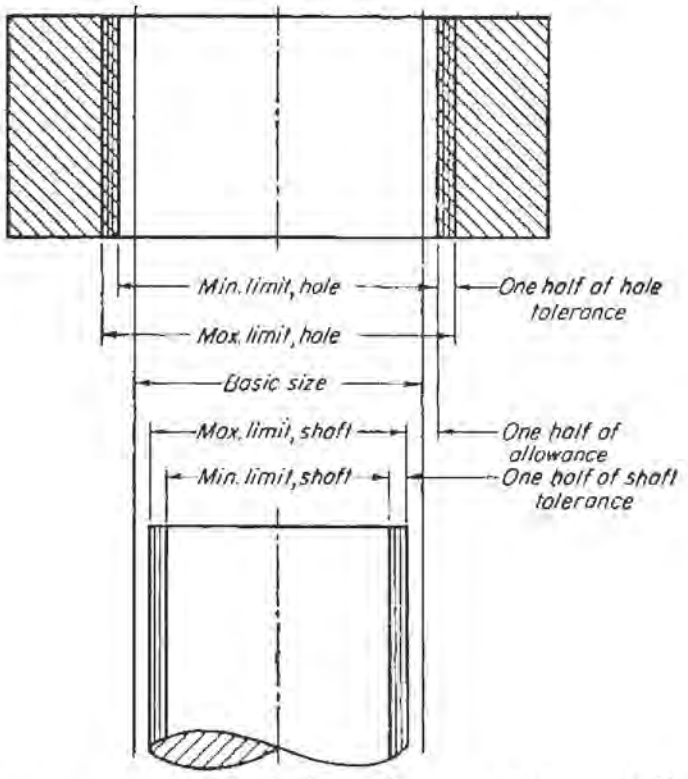


Fig. 4.2 Illustration of basic size, tolerance, limits, and allowance.

Basic size: Basic size is the theoretical size to which allowance and tolerance are applied to determine limits. The basic size in Fig. 4.1 is 2.250 in.

Allowance: Allowance is an intentional difference in the sizes of mating parts. Dimensionally, it is the difference between the

smallest permissible hole or external member and the largest permissible shaft or internal member. The allowance depends on the size of parts in a fit, the function of the parts, and the relative speed between moving parts; and its application results in different classes of fit. The allowance is said to be negative when the shaft is smaller than the hole and positive when the shaft is larger than the hole. The allowance in Fig. 4.1 is

$$2.250 \text{ in.} - 2.246 \text{ in.} = 0.004 \text{ in.}$$

Tolerance: Tolerance is a permissible variation in the size of a part to accommodate unavoidable variations in the manufacturing process and in the successive units of material. In amount, it is the difference between the maximum and minimum permissible dimensions of a part. The tolerance for the hole in Fig. 4.1 is 2.253 in. − 2.250 in. = 0.003 in.; for the shaft it is

$$2.246 \text{ in.} - 2.243 \text{ in.} = 0.003 \text{ in.}$$

Limits: Limits are the maximum and minimum permissible dimensions of a part. In Fig. 4.1, the hole limits are 2.253 and 2.250 in., and the shaft limits are 2.246 and 2.243 in.

Basic-hole and Basic-shaft Systems

Two systems are in use for prescribing the basic sizes of fits. They are:

Basic-hole system: The dimension of the minimum hole is the basic size in this system. All of the tolerance in the hole is above basic size. The shaft is made larger than the basic size for interference fits and smaller than basic size for clearance fits. The latter condition is illustrated in Fig. 4.1.

Basic-shaft system: The dimension of the maximum shaft is the basic size in this system. In principle, it is the reverse of the basic-hole system.

Classes of Fit

Different classes of fit are needed to perform the various functions of mating parts. Three groups of fit in one classification consist of:

Clearance fits: Clearance fits are fits in which assembled parts are free to move relative to each other because they have a certain amount of clearance; that is, because the internal member is smaller than the external member. The allowance in these fits is positive.

Interference fits: Interference fits are fits in which assembled parts are more or less permanently fixed relative to each other because their sizes overlap; that is, because the internal member is larger than the external member so that force must be applied to assemble them. The allowance in these fits is negative.

Transition fits: Transition fits are fits in which the application of tolerance may result in either clearance or interference between parts when they are assembled.

Another classification lists running, sliding, push, driving, and force fits. A *running fit* is one in which an allowance is made so that a shaft will be free to rotate in a bearing. A *sliding fit* is one in which one part, such as a transmission gear, must be free to slide on its mating shaft. A *push fit* is one in which the parts must assemble by hand but show no perceptible shake after assembly. A *driving*, or *light force fit* is one in which parts are more or less permanently assembled by forcing them together with light pressure. A *force fit* is one in which parts are permanently assembled by forcing them together with heavy pressure. Shrink or expansion fits may be preferable to force fits for making some permanent assemblies. In making a shrink fit, the external member is expanded by heating it. Then it is shrunk in place after the parts have been assembled. In making expansion fits, the internal member is cooled to shrink it. Then it is expanded after assembly with the hole.

Unilateral and Bilateral Dimensioning

Two systems, with several variations in each, may be used to dimension a drawing with tolerance or limits.

Unilateral dimensioning: Unilateral dimensioning is a system of dimensioning in which all of the tolerance is indicated on one side only of the basic size.

Bilateral dimensioning: Bilateral dimensioning is a system of dimensioning in which parts of the tolerance, usually equal amounts,

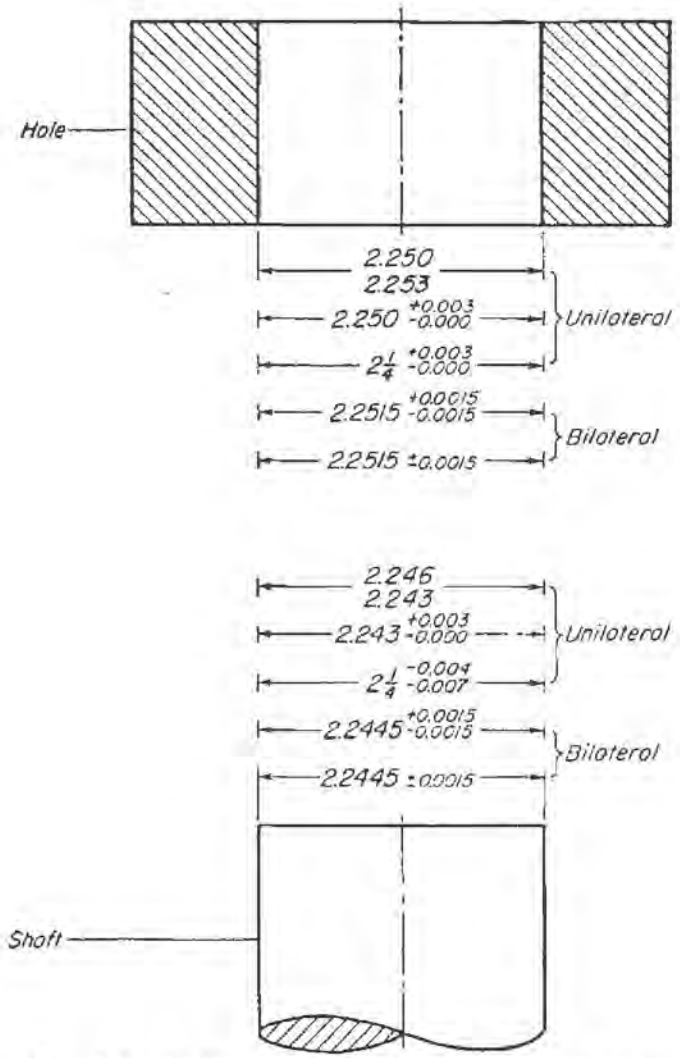


Fig. 4.3 Unilateral and bilateral dimensioning.

are indicated on both sides of the basic size. These two systems of dimensioning, and their variations, are illustrated in Fig. 4.3.

Interchangeable and Selective Assembly Manufacturing

Fits between mating parts may be accomplished in two ways:

1. By fitting the parts to each other during machining and assembly operations. This is a slow and expensive procedure that produces fits in specific assemblies, but it does not provide the interchangeability of parts which is necessary for mass production.

2. By interchangeable and selective assembly manufacturing. Interchangeable assembly is applicable to the assembly of clearance

fits. As the term is commonly used, interchangeable manufacturing means that mating parts are machined to be so nearly alike dimensionally that they may be drawn at random from among a number of like parts which have been produced, and may be assembled without individual fitting. Interchangeability is secured by following a systematic plan:

1. International,[1] national,[2] and industrial standards have been established that designate limits for each class and size of fit which is to be produced. These limits must be adhered to in manufacturing mating parts.

2. Drawings are dimensioned to indicate the limits, standardized as above, for each part that is to be manufactured.

3. Limit gages are used to measure the work. Notice that the size of a part should lie between two limits and that workmen and inspectors are not concerned with its actual size.

4. Parts that are manufactured and pass inspection under this plan may be assembled without individual fitting; that is, they will be interchangeable.

Selective assembly is applicable to the assembly of interference fits. Recall that shafts are larger than holes and that force must be applied to assemble these fits. However, a maximum shaft assembled with a minimum hole will overstress the parts, and a minimum shaft assembled with a maximum hole will understress them. Therefore, a process of selection is added to the method which has been described for producing interchangeable parts. This consists of separating holes and shafts into two, three, or more groups of each during inspection in order that the largest shafts may be assembled with the largest holes, and so on, for each group which is established.

[1] Reprint, in English, of International Standards Association Bulletin 25.

[2] "American Standard Preferred Limits and Fits for Cylindrical Parts. ASA B4.1-1955."

The foregoing standards are published by The American Society of Mechanical Engineers, New York.

QUESTIONS

1. Name the terms applying to metal fits that are defined below.

(*a*) The condition of clearance or interference that exists between the mating parts of an assembly.
(*b*) The amount of variation that is permissible in the size of the manufactured part.
(*c*) The maximum and minimum dimensions between which the size of a part is permitted to vary.
(*d*) The difference between the minimum permissible hole and the maximum permissible mating shaft that constitute a fit.

2. Define the terms: "interchangeable assembly manufacturing" and "selective assembly manufacturing."

5

NONPRECISION MEASURING TOOLS

REFERENCE SURFACES

The measuring tools that are used by inspectors may be classified, roughly, in two groups as:

1. Nonprecision tools.
2. Precision tools.

Nonprecision linear measurements are made with steel rules that are commonly graduated in the binary divisions of halves, quarters, eighths, sixteenths, thirty-seconds, and sixty-fourths of an inch, and in the decimal divisions of tenths, fiftieths, and hundredths of an inch. Calipers and similar tools are used to transfer measurements from steel-rules to work and vice versa.

Precision linear measuring tools are instruments that are capable of measuring to thousandths, ten-thousandths, and finer decimal divisions of an inch.

Nonprecision angular measurements are made with squares, bevels, and protractors that read to degrees.

Precision angular measurements are made with accurate squares and angle gages, protractors that read to five minutes, dividing heads, and tools and methods which are based on the use of trigonometry.

Steel Rule

The steel rule, or "scale," is the basic nonprecision linear measuring tool. It may be used alone for the direct measurement of lengths; it may be used with calipers and other tools for comparison measurements; and it may be used as a straightedge.

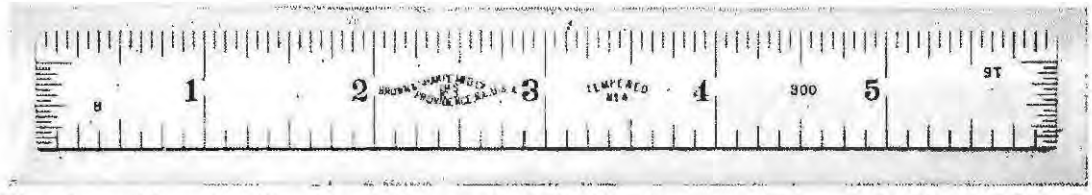


Fig. 5.1 "Standard" spring-tempered steel rule. *Courtesy of Brown & Sharpe Mfg. Co.*

A steel rule is a thin strip of steel that is graduated on one or more of its edges and, sometimes, on its ends also. Divisions are spaced accurately enough so that a skilled operator can measure to within five to seven thousandths of an inch of a given dimension. However,

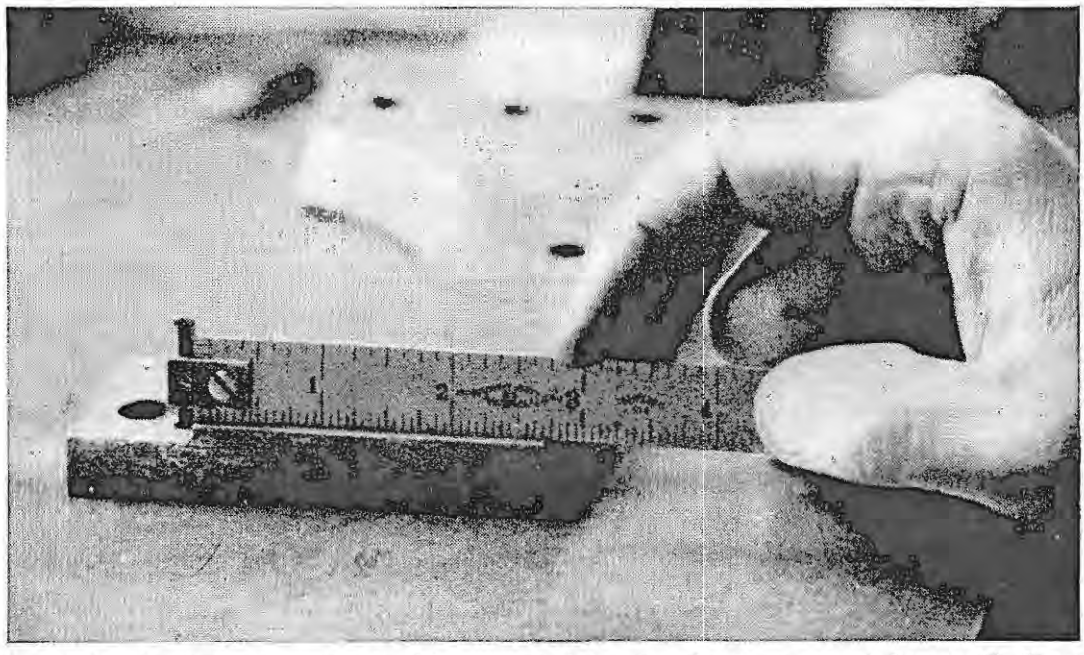


Fig. 5.2 Application "standard" tempered hook rule. *Courtesy of Brown & Sharpe Mfg. Co.*

he does not know to what thousandth he measures; and when that knowledge is required, he must use a precision measuring tool. Standard graduations, as furnished by most manufacturers of these tools, are listed in Table 2.

Steel rules are made in lengths of ¼ to 48 in., and their other

characteristics vary according to the principal use for which they are intended. A "standard" 6-in. tempered steel rule, often carried as a pocket rule by mechanics and inspectors, is illustrated in Fig. 5.1. Narrow tempered steel rules, not as wide as "standard," are

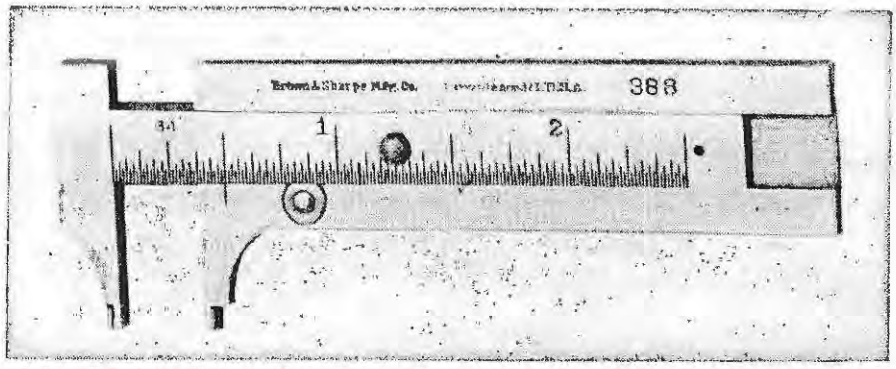


Fig. 5.3 Pocket slide caliper rule, front. *Courtesy of Brown & Sharpe Mfg. Co.*

designed for insertion in small holes and slots; and flexible steel rules, thinner than "standard" and tempered for flexibility, may be bent to follow and measure along a contour.

Some steel rules are fitted with attachments to adapt them for doing particular jobs. "Standard" and narrow-tempered hook

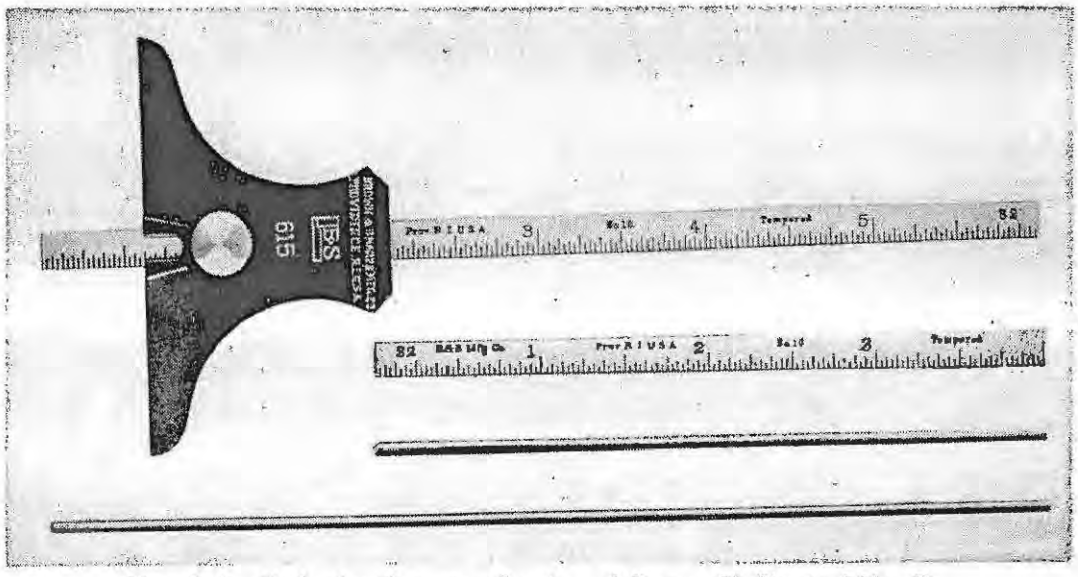


Fig. 5.4 Rule depth gage. *Courtesy of Brown & Sharpe Mfg. Co.*

rules are fitted with a hook on one end for measuring to shoulders, grooves, etc., as illustrated in Fig. 5.2. Short steel rules with a holder are useful for reaching into and measuring in narrow recesses. A pocket slide caliper rule, illustrated in Fig. 5.3, is useful for

measuring outside and inside diameters of small rods, tubes, etc. The rule depth gage, Fig. 5.4, has an adjustable head that aids in measuring depths of holes, and the tool may be furnished with rods that will enter holes too small to be measured with its rule.

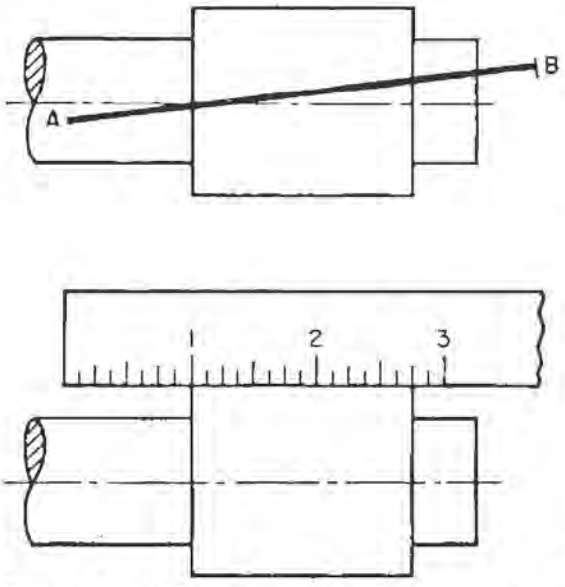


Fig. 5.5 Use of steel rule to measure between shoulders.

It is important to employ a rule properly if accurate measurements are to be secured from its use. In the front view of Fig. 5.5, the application of a steel rule to measure the length between two shoulders on a shaft is illustrated. Notice that the one-inch mark on the rule is aligned with the left-hand shoulder of the work. This is done to avoid the difficulty of aligning the end of a rule with such a surface and to avoid possible error because of a worn corner on the rule. Be sure to read a fractional measurement in its lowest term. The measurement in this example should be read 1¾ in., not 1⅞ in. Be sure, also, to measure along a line that is parallel to the axis or edge of work, and not along an angular line.

In measuring to a shoulder, it is proper to place the end of the rule against the shoulder because a worn corner will not affect the reading. In an application of this kind, be sure that the end of the rule is fully seated on the shoulder.

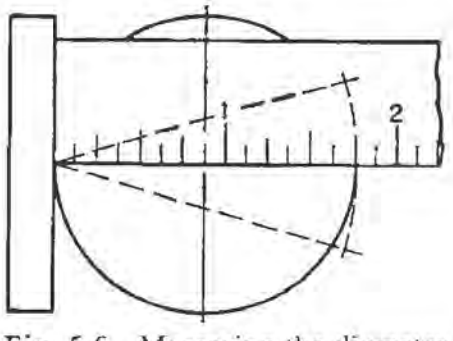


Fig. 5.6 Measuring the diameter of a shaft with a steel rule.

In Fig. 5.6, the use of flat stock as a reference surface when measuring the diameter of a shaft is illustrated. Butt the end of the rule against the stock, in the position shown, and move the opposite end of the rule in an arc to locate and measure the diameter. The diameter of a hole is measured with a

rule in much the same way. Tip the rule at a slight angle so that the corner of the tool may be placed against the edge of the hole and move the rule in an arc to locate the diameter.

Another direct application of the steel rule is its use as a straightedge to test flatness or planeness of a surface. The test is made by drawing the edge of the rule over the surface: (*a*) longitudinally, (*b*) transversely, and (*c*) diagonally. The rule and surface being tested are viewed against a source of light so that low spots on the work will be disclosed by light showing under the rule.

Regular straightedges are not graduated, and they may be made of unhardened steel, of hardened steel, or of cast iron. Toolmakers' straightedges, for work requiring great accuracy, are made with knife edges to provide line contact with surfaces being tested.

Care of the steel rule

Although the steel rule has been classed as a nonprecision tool, it should be well cared for if satisfactory results are to be obtained from its use. Do not cause undue wear by laying the rule in dirty, abrasive material. Do not destroy the accuracy of its graduations by allowing the tool to rust. Do not use the rule as a screw driver. Do not use it as a scraper. Clean the rule after use so that it will not etch from perspiration.

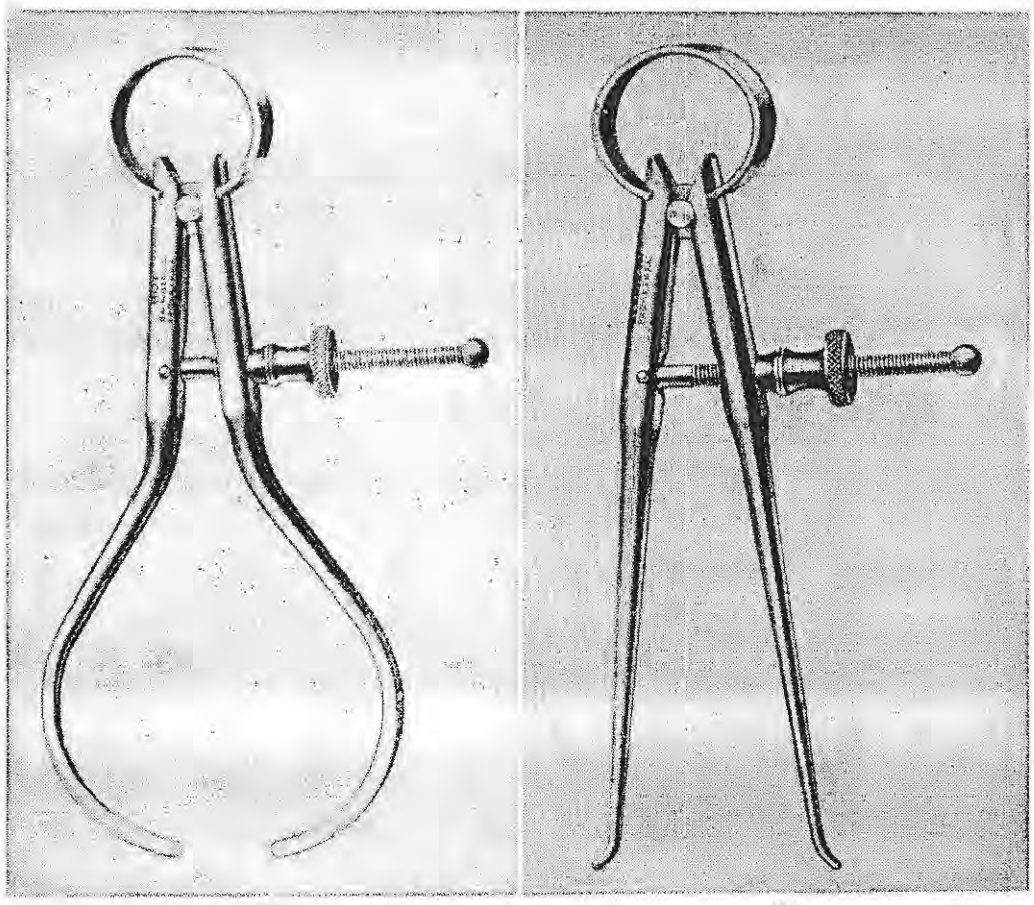
These general suggestions should be followed in caring for all measuring tools: (*a*) keep work and tools clean; (*b*) do not abuse tools through careless or improper use; and (*c*) clean tools and wipe them with a rust preventive after use.

Calipers

A caliper, or "calipers," is a tool with two adjustable legs that is used to measure such distances as the outside diameter of a shaft, the inside diameter of a hole, lengths between shoulders, and similar dimensions. Outside and inside toolmakers' spring calipers, which have the advantage that they may be set to size quickly and accurately by means of their screw adjustment, are illustrated in Fig. 5.7. The legs, of round steel, are tapered by swaging to make

well-balanced tools suitable for use in toolmaking and other accurate work. This style of caliper is made with legs 2 to 6 in. long. Less expensive spring calipers, with legs made of flat steel, are made in 4- to 8-in. sizes.

Firm-joint outside and inside calipers, shown in Fig. 5.8, are set to size by tapping one leg against a solid metal object in a direction



(*a*) (*b*)

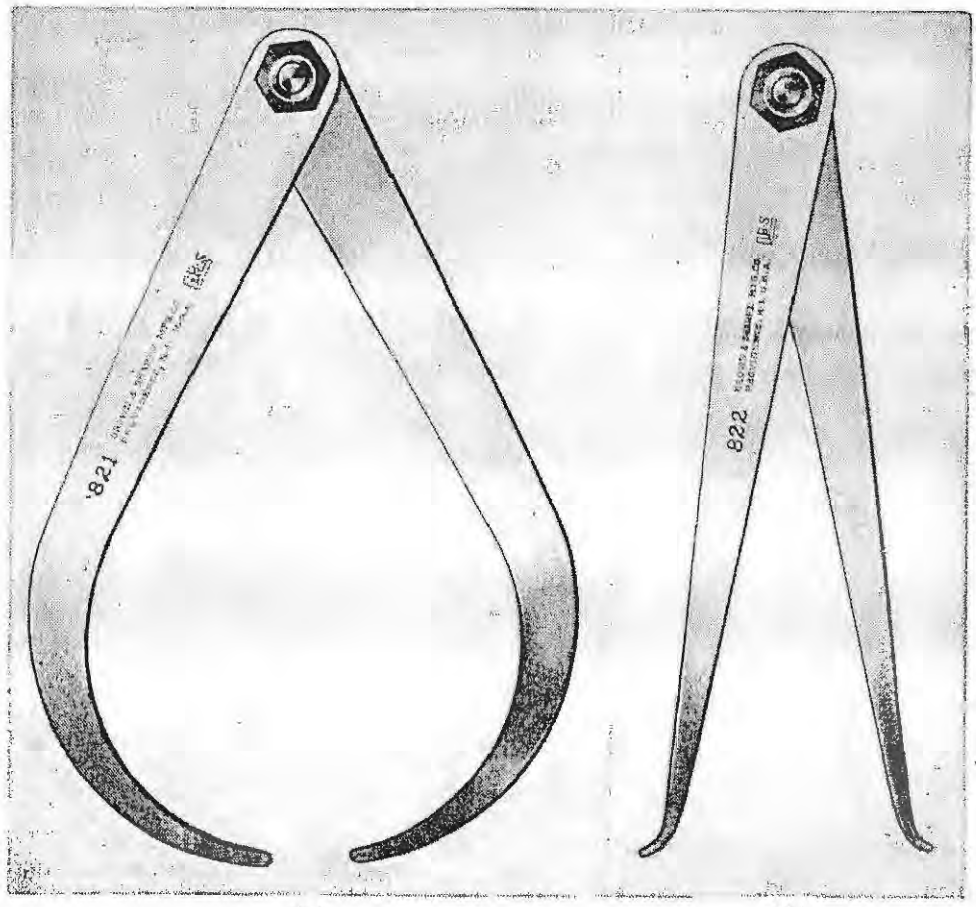
Fig. 5.7 Toolmakers' spring calipers: (*a*) outside, (*b*) inside. *Courtesy of Brown & Sharpe Mfg. Co.*

that will open or close the tool as desired. This style of caliper is made in sizes from 6 to 24 in.

Transfer firm-joint calipers have one regular caliper leg and one two-part leg that consists of: (*a*) an auxilliary leaf which acts as a stop and (*b*) a transfer caliper leg. With this construction, the caliper may be set to size; the transfer leg may be moved away from the stop to clear any obstruction on the work; and the leg may be

reset to size against the stop, when in a clear position, for the measuring operation.

A caliper may be used in either of two ways: first, the caliper may be set to a steel rule or other measuring tool, and then used to gage the work; or second, the caliper may be set to the work, and



(*a*) (*b*)

Fig. 5.8 Firm-joint calipers: (*a*) outside, (*b*) inside. *Courtesy of Brown & Sharpe Mfg. Co.*

then compared with the measuring tool to determine the dimension. The caliper must be set and compared with the work and measuring tool very carefully if accurate results are to be obtained. In using a caliper, the sense of touch is important to the inspector because the tool must be set until he just feels contact as it passes over the work. The inspector should develop this sense through practice. An outside caliper is set to a steel rule by holding the contact point of one caliper leg against the end of the rule and by setting the contact point of the other leg to "split the line" of the

required graduation. Hold the tools in a position such that shadows are avoided and graduations on the rule may be seen clearly. An inside caliper may be set by placing one contact point against the hook of a hook rule or by butting the contact point and the end of a "standard" rule against a machined surface while the setting operation is performed.

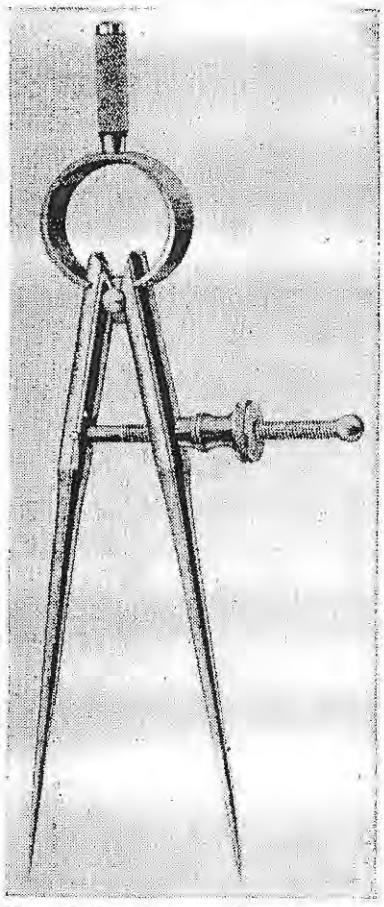


Fig. 5.9 Toolmakers' spring dividers. *Courtesy of Brown & Sharpe Mfg. Co.*

A divider (Fig. 5.9) is used to transfer measurements from a rule to points on work, or vice versa, and to draw arcs and circles. To set a divider, place one of its measuring points in a graduation on a steel rule, then adjust the tool until the other measuring point is felt to enter a second graduation at the required distance from the first. A trammel, or beam divider (Fig. 5.10) is used for similar work that is beyond the range of a divider.

A hermaphrodite caliper (Fig. 5.11) consists of one inside caliper leg and one divider leg. It is used to

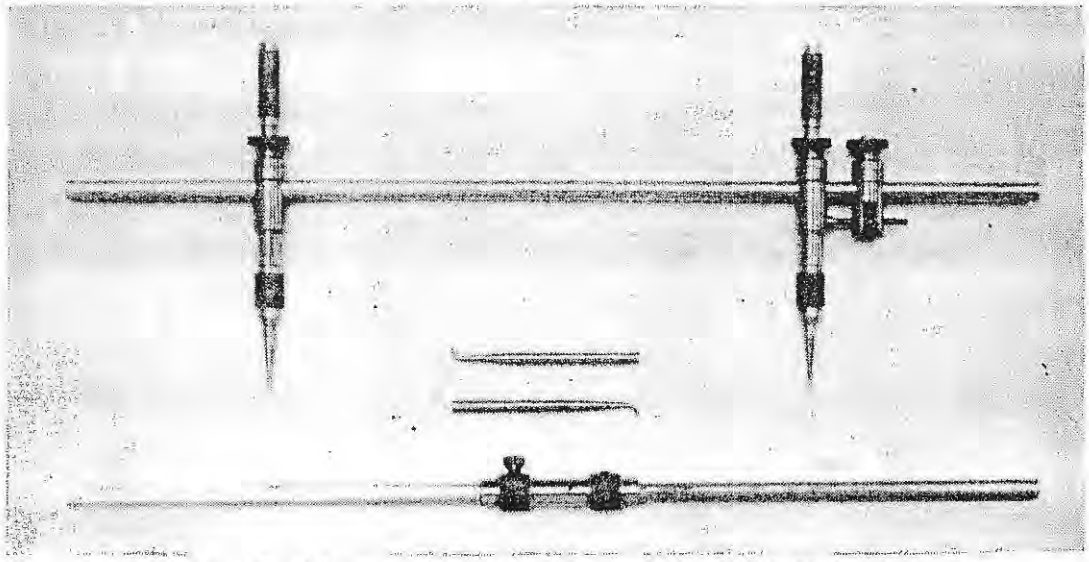


Fig. 5.10 Steel beam trammel. *Courtesy of Brown & Sharpe Mfg. Co.*

locate centers on the ends of round bar stock and to draw lines on work parallel to one or more of its edges.

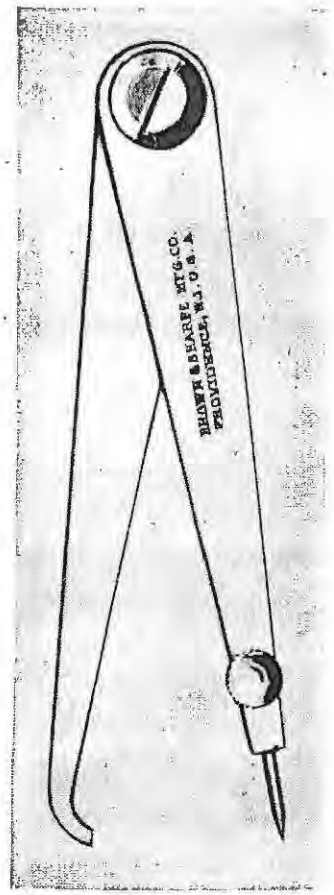


Fig. 5.11 Hermaphrodite caliper. *Courtesy of Brown & Sharpe Mfg. Co.*

Nonprecision Angular Measurements

Angles are usually measured in degrees, minutes, and seconds in industrial work.

60 seconds (″) = 1 minute (′)
60 minutes = 1 degree (°)
45 degrees = 1 miter angle
90 degrees = 1 right angle
360 degrees = 1 circle

30- and 60-deg angles are frequently used in industrial work also.

Nonprecision angular measurements are made with adjustable squares, combination squares, bevel protractors, bevels, and angle gages.

An adjustable square is shown in Fig. 5.12. It consists of a graduated blade (essentially a steel rule) with a clamping groove on one side, a head that may be adjusted anywhere along the blade, and a bolt for clamping the head to the blade. Some of these tools come equipped with an auxiliary blade with a 45-deg angle on one end and a 30-deg angle on the other end. A nonprecision test for the squareness of tools like this consists of placing the head of the square against a machined edge, such as the sheared edge of a piece of sheet metal, and scribing a line along the edge of the blade. The head of the square is then reversed in its position on the machined edge, and the blade is checked with the line previously drawn. If the blade agrees with the line all along its length, the tool is square.

A combination square (Fig. 5.13) is an adjustable square also. Its head, however, is constructed to measure both 90- and 45-deg angles. The combination square is adaptable to several uses other

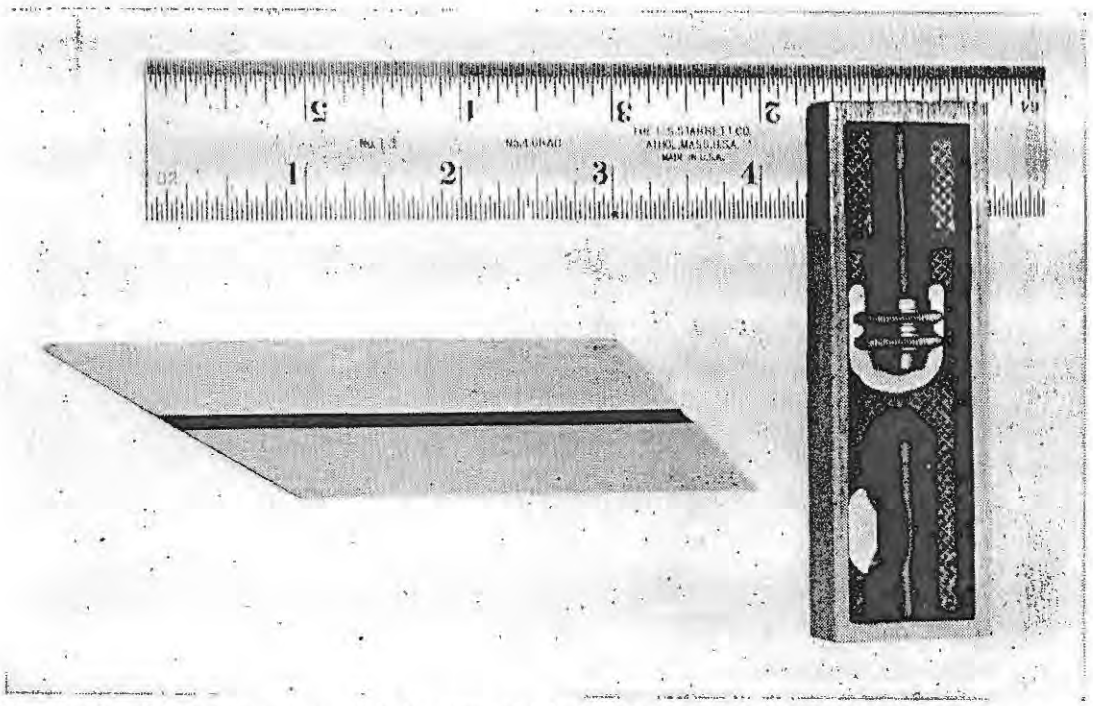


Fig. 5.12 Double square with hardened blade. *Courtesy of The L. S. Starrett Company.*

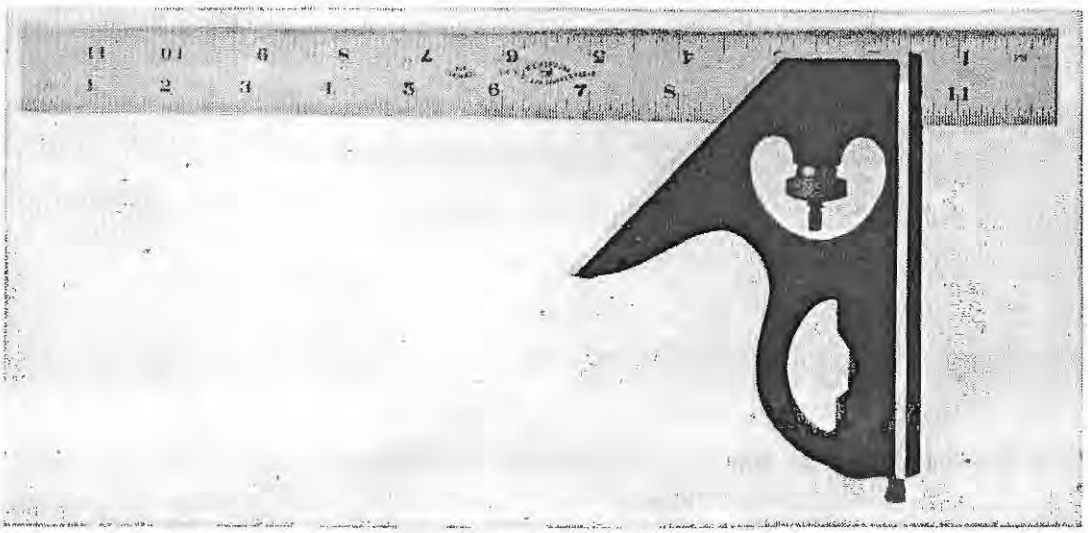


Fig. 5.13 Combination square. *Courtesy of Brown & Sharpe Mfg. Co.*

than measuring angles. It may be used alone as a depth gage; it may be used with a scriber as a marking gage; and attachments are available that fit it for use as a depth gage or as a height gage.

Bevel Protractor and Bevel

When angles other than 45 and 90 deg must be compared or measured, a bevel protractor or bevel may be used. A bevel protractor (Fig. 5.14) consists of a blade and a protractor head. The

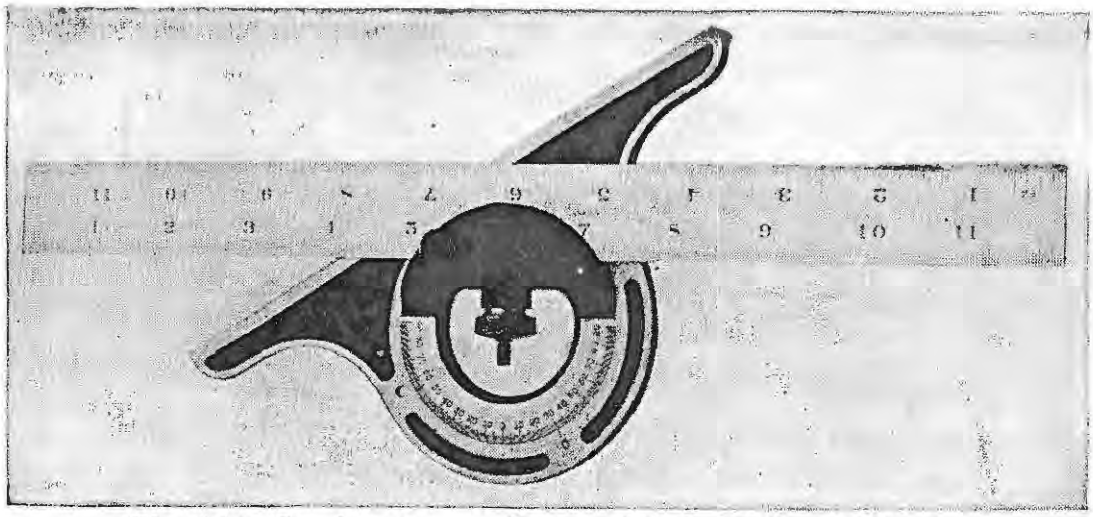


Fig. 5.14 Bevel protractor. *Courtesy of Brown & Sharpe Mfg. Co.*

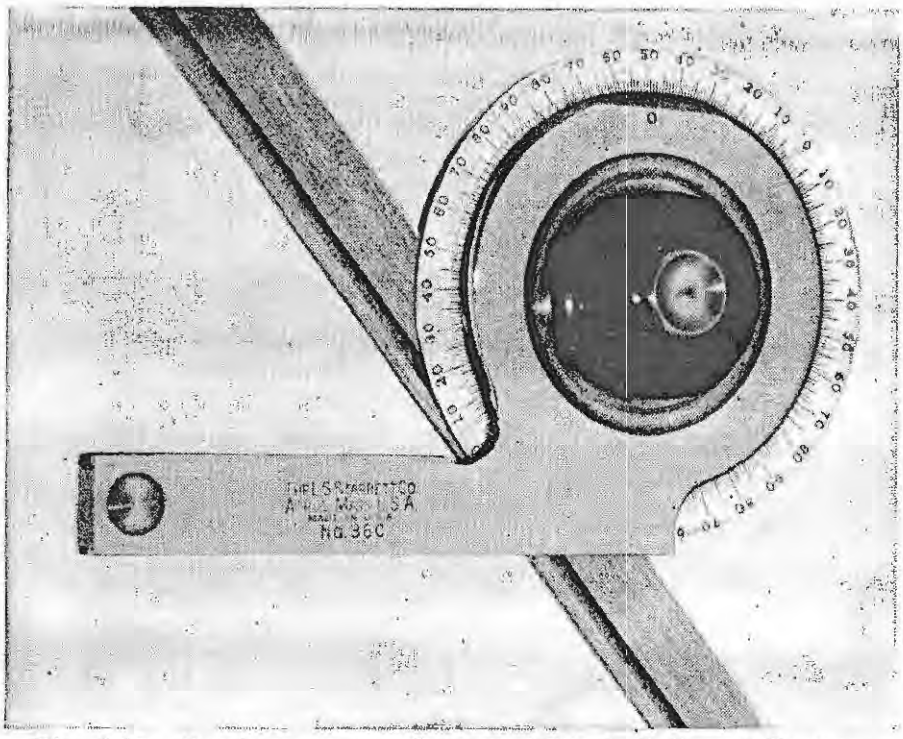


Fig. 5.15 Bevel protractor. *Courtesy of The L. S. Starrett Company.*

base of the protractor head may be set at any angle to the blade by adjusting it on the turret which is graduated in degrees. Another style of bevel protractor that is useful for measuring angles on flat surfaces is shown in Fig. 5.15.

A combination set joins a combination square, bevel protractor, and center square in one tool. The latter tool is used to locate centers on the end of round bar stock.

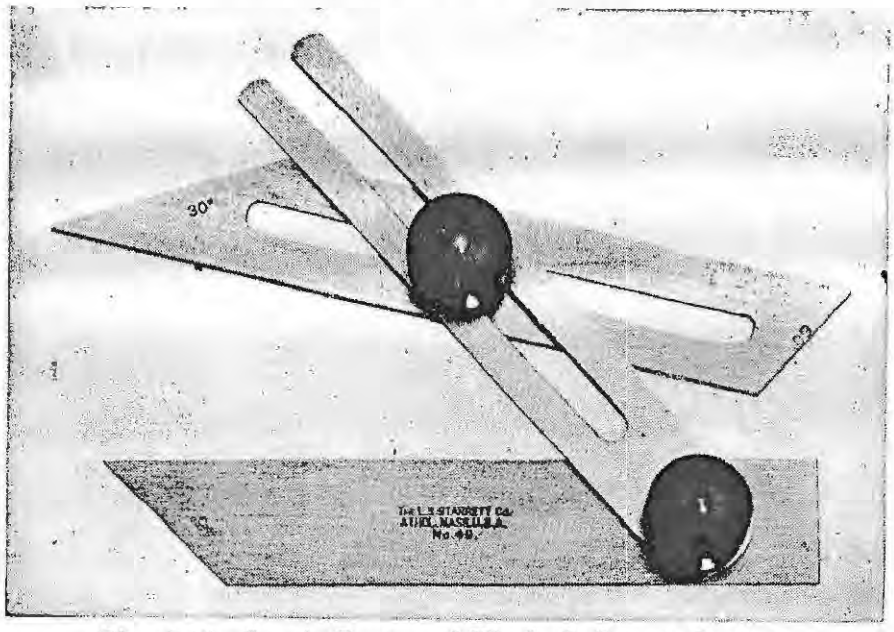


Fig. 5.16 Bevel. *Courtesy of The L. S. Starrett Company.*

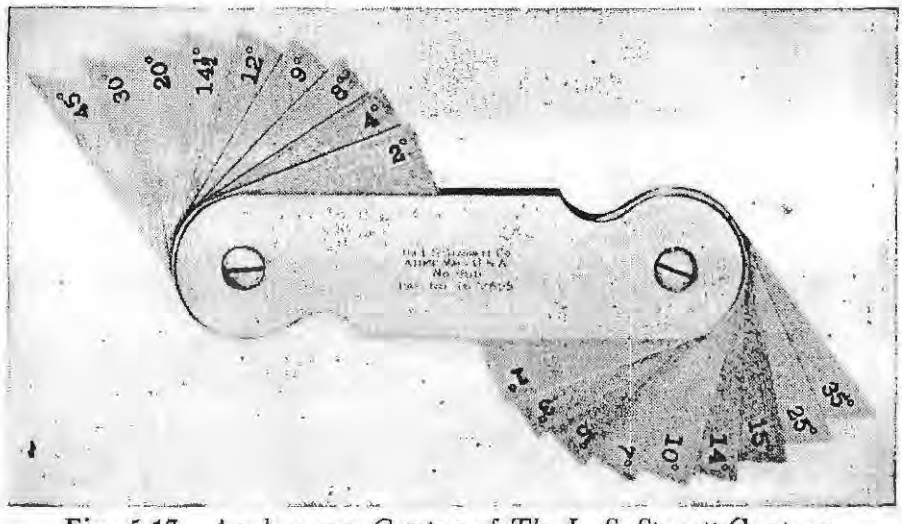


Fig. 5.17 Angle gage. *Courtesy of The L. S. Starrett Company.*

The bevel is a tool that has two or three blades which are adjustable at various angles to each other. The tool shown in Fig. 5.16 may be set at 90-, 45-, 60-, and 30-deg angles by using the ends of the blades as reference surfaces. Other angles may be secured by setting the tool to a bevel protractor.

The angle gage (Fig. 5.17) has eighteen leaves with their ends cut at various angles of from 2 to 45 deg.

Contour Measurements

Simple fillets and rounds on work may be inspected with fillet and radius gages similar to that shown in Fig. 5.18. More complex

contours may be tested with special templets or gages made of sheet metal or flat stock to the shape required.

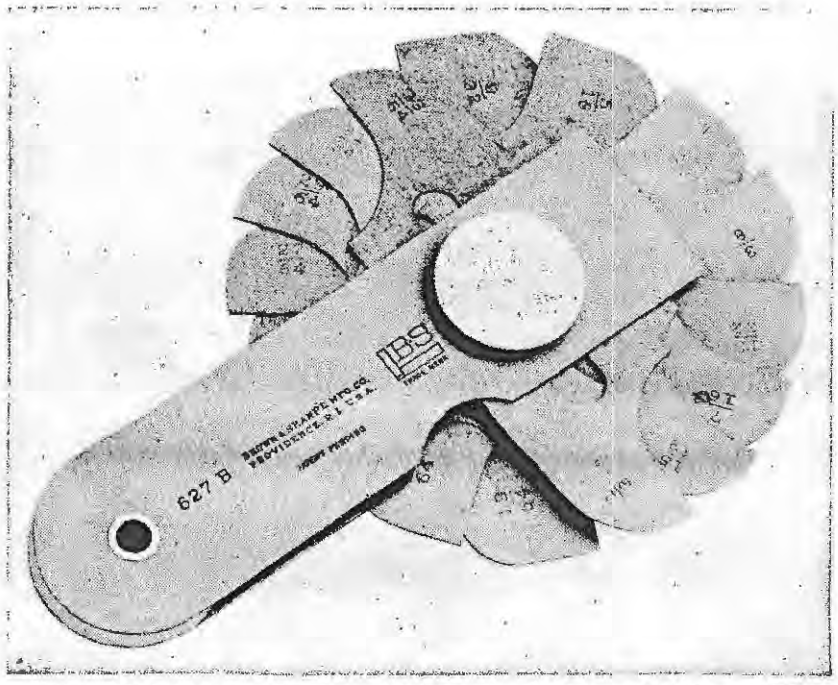


Fig. 5.18 Fillet and radius gage. *Courtesy of Brown & Sharpe Mfg. Co.*

Reference Surfaces

Many parts must be positioned for inspection so that measurements may be referred to a base surface. For example, the distances H_1 and H_2 in Fig. 5.19 may be measured most conveniently by resting the base surface S on a horizontal plane that extends to the region M; center distances C_1 and C_2 may be measured most conveniently by mounting the base surface S on a surface that is perpendicular to the horizontal surface. Reference surfaces for inspection operations like these consist of surface plates, angle plates, and related accessories.

Surface Plates

A surface plate provides a horizontal reference surface on which work may be mounted for inspection. These plates may be made of cast iron, heat-treated steel, ceramic material, glass, or granite; and their reference surfaces may be finished by scraping, grinding, or lapping.

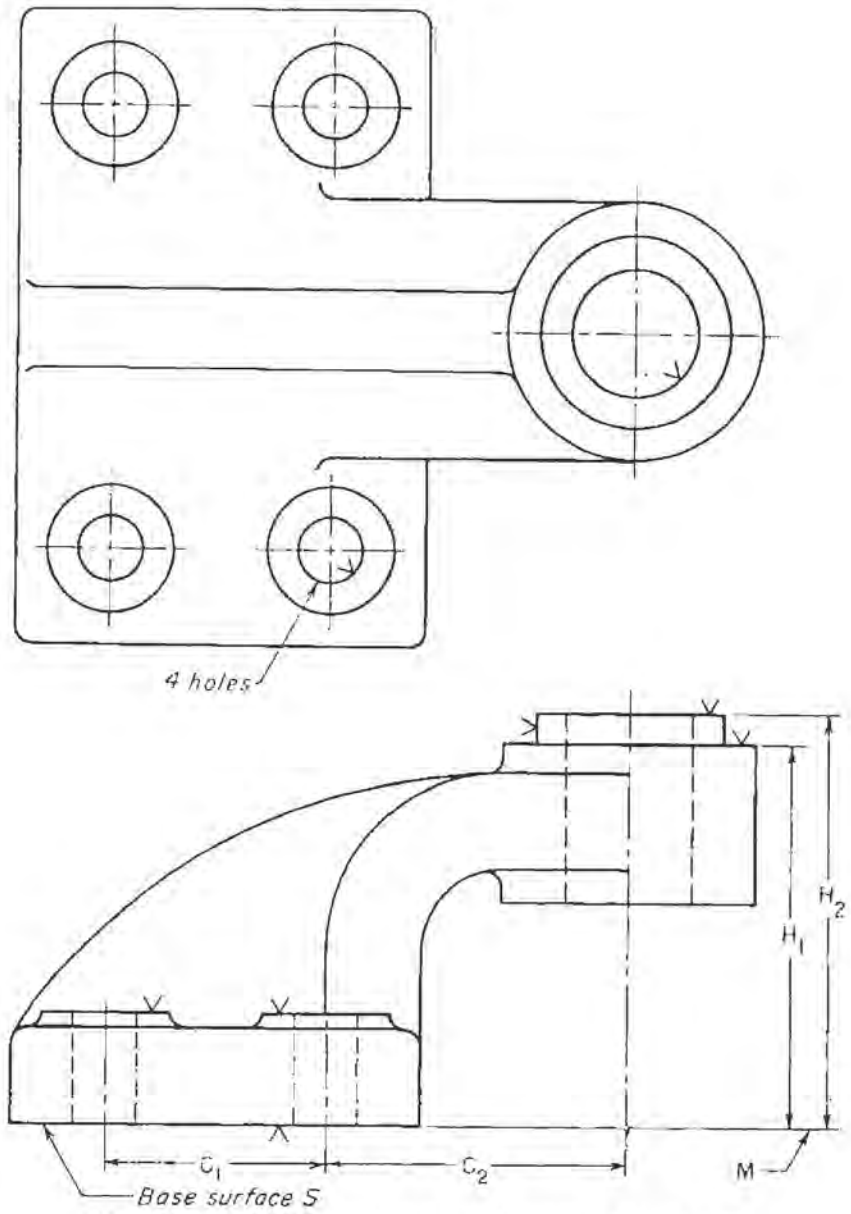


Fig. 5.19 Work requiring a reference-surface setup.

A cast-iron surface plate is shown in Fig. 5.20. The reference surface on this plate is finished by planing, seasoning, and scraping. *Planing* is a metal cutting operation that generates flat or plane surfaces by moving a single-point cutting tool in a straight line across the work or vice versa; *seasoning* is an ageing process that gives stability of form and size to the metal; and *scraping* is a hand-finishing process that is used to produce accurate surfaces on metals by removing minute amounts of material from high spots at each stroke of a cutting tool called a scraper. Scraped surface

plates are usually finished to within 0.0002 in. of a true plane. The under side of a cast-iron surface plate is heavily ribbed to give it stiffness and rigidity.

Ceramic, glass, and granite surface plates are finished by lapping to an accuracy of 0.0001 in. or less, and are claimed to be of superior quality in stability, wearability, resistance to damage by impact, and other desirable features.

In addition to its use as a reference surface for linear and angular measurements, a surface plate may be used to test the flatness of

Fig. 5.20 Top of a cast-iron surface plate showing hand-scraped surface. *Courtesy of The Taft-Pierce Manufacturing Company.*

other plane surfaces. To do this, the surface plate is covered with a thin coat of a coloring paste that is made by mixing red lead, prussian blue, or lampblack with oil. Then the part being tested is rubbed over the coated surface. High spots on the work will pick up color from the surface plate, and these spots may be removed by scraping to produce a true surface.

A *toolmakers'* or *master flat* is a precision surface plate made of alloy steel that is heat-treated, ground, and lapped to a plane surface which is accurate to 0.00001 in.

A bench block, or bench plate, is similar to a cast-iron surface plate. Its reference surface, however, is planed or ground only; and it is not as accurate as a surface plate.

When a surface, or bench plate, is not available, work may be set up on a milling machine or planer table while it is inspected.

Surface Gage

A surface gage, illustrated in Fig. 5.21, is often used when inspecting work that is set up on a surface plate. Fine adjustment of

the scriber, for vertical measurements above the reference surface, is obtained with a screw at one end of the bracket that holds the spindle as shown in the illustration. Gage pins in the base may be pushed down to guide the tool along an edge of the reference surface when doing line work. A V groove in the base of the tool adapts it for use on cylindrical as well as on flat surfaces.

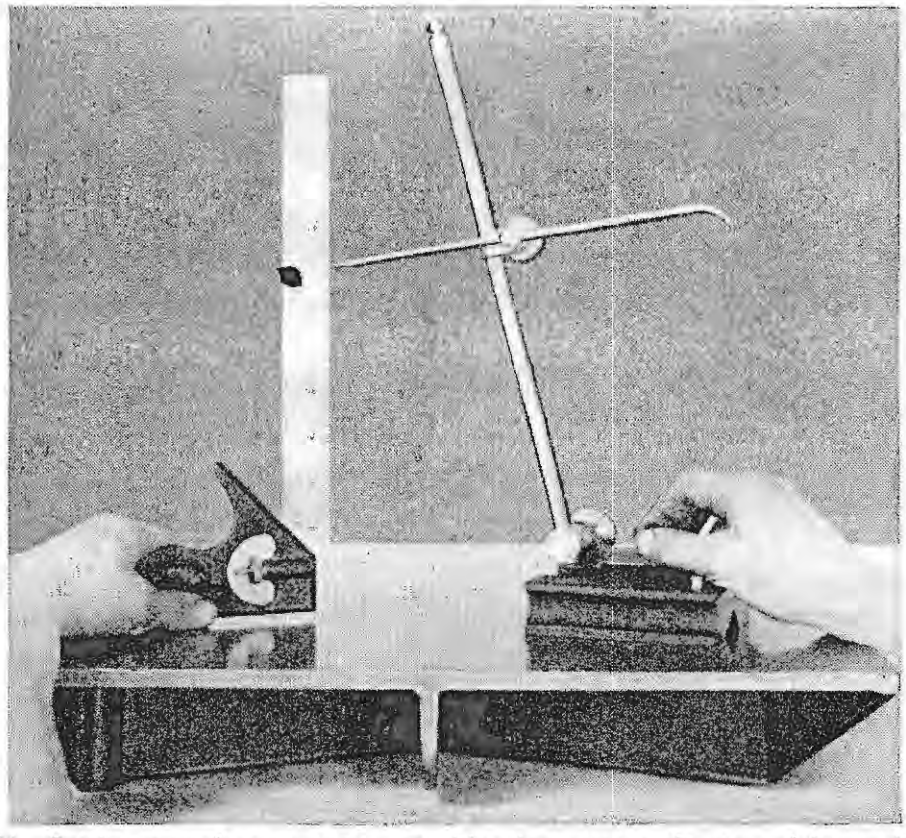


Fig. 5.21 Setting a surface gage to a combination square. *Courtesy of Brown & Sharpe Mfg. Co.*

Angle Plate, Angle Iron, or Knee

When a vertical reference surface is required by the work to be inspected, it may be obtained by placing an angle plate, angle iron, or knee, on a surface plate. These three terms are used synonymously to describe an iron casting that has two finished surfaces, usually at 90 deg to each other, as illustrated by the toolmakers' knee shown in Fig. 5.22. If a reference surface at other than 90 deg is required, it may be secured by using an adjustable knee or by making a special, solid knee having the wanted angle.

Work must usually be fastened to a knee while it is being in-

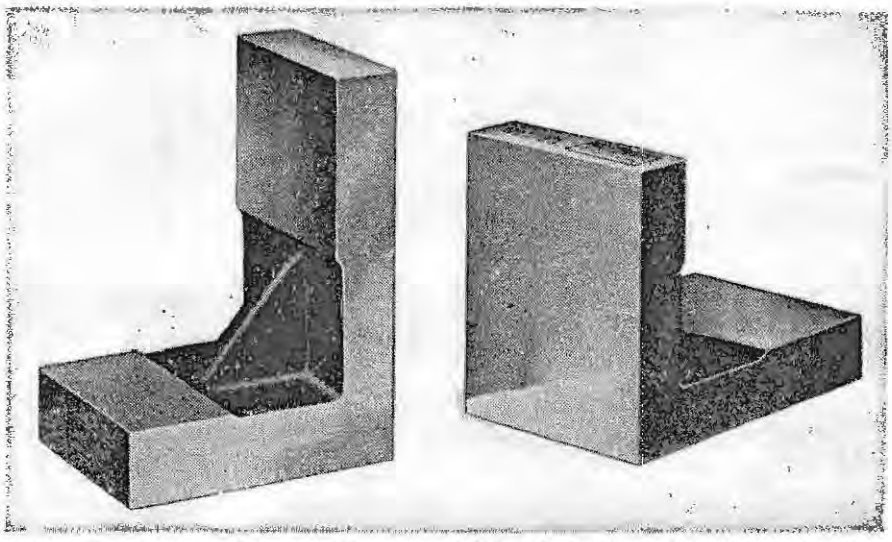


Fig. 5.22 Toolmakers' knee. *Courtesy of The Taft-Pierce Manufacturing Company.*

spected, and parallel clamps, or C clamps, are commonly employed for this purpose.

Parallels

Sometimes a part of the work to be set up on a surface plate for inspection will rest on the reference surface while another part must be supported at some distance above it to secure stability. Parallels, made of steel or cast iron, and finished to a rectangular form in varying degrees of accuracy, are used to provide the support in cases of this kind. Steel parallels, accurately ground to size after heat treating, are illustrated in Fig. 5.23. When regular parallels

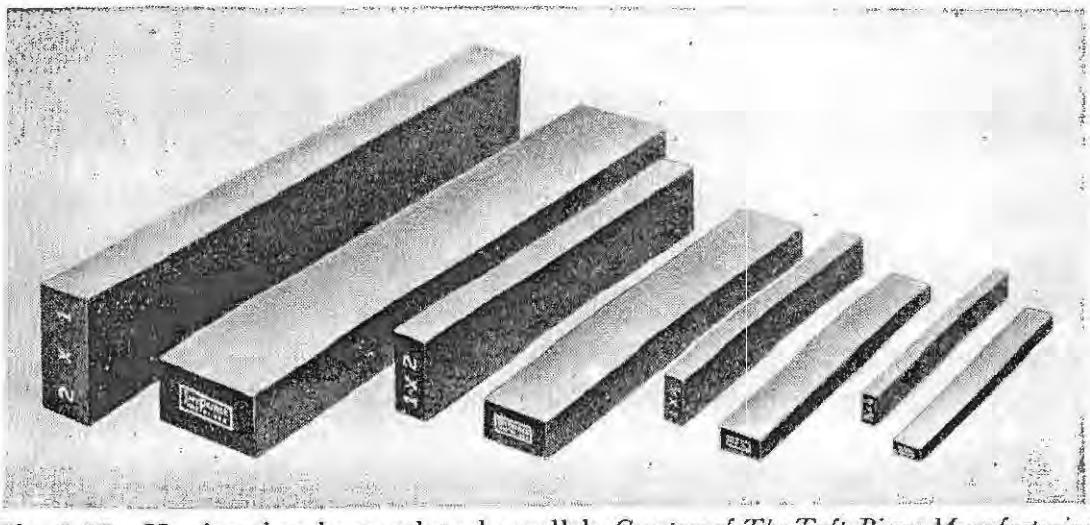


Fig. 5.23 Hardened and ground steel parallels. *Courtesy of The Taft-Pierce Manufacturing Company.*

are not available, cold-finished rectangular bar stock or ground flat stock, cut to appropriate lengths, may be used. Thickness gage or feeler stock, which is manufactured in thicknesses ranging from 0.0015 to 0.015 in. is useful in setups of this kind also.

V Blocks

Many cylindrical work pieces may be held with V blocks mounted on a surface plate, as illustrated in Fig. 5.24, for inspection. The

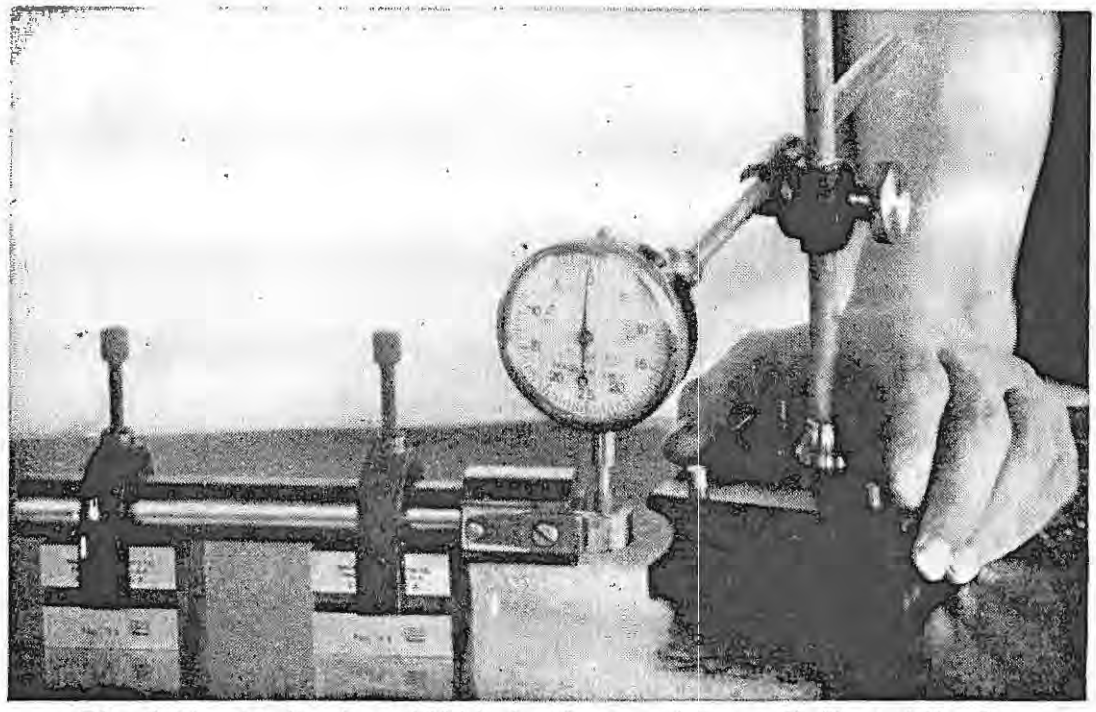


Fig. 5.24 Application of V blocks. *Courtesy of Brown & Sharpe Mfg. Co.*

work may be set up horizontally, as shown, or the V block may be turned on end to hold it vertically when the job requires it.

V blocks for general use are made of cast iron, but those for more accurate work are made of hardened steel carefully finished by grinding. Mating blocks are made and sold as matched pairs. Blocks are grooved on their sides to receive the clamps which are furnished with them.

Bench Center

A bench center, illustrated in Fig. 5.25, is used to hold cylindrical work on centers so that it may be rotated, by hand, to test its con-

centricity and to check the runout of its shoulders. The bench center consists of a lathe-like bed, headstock, footstock, and a holder for mounting a dial test indicator with which to test the work piece. Dial indicators are described in Chap. 9.

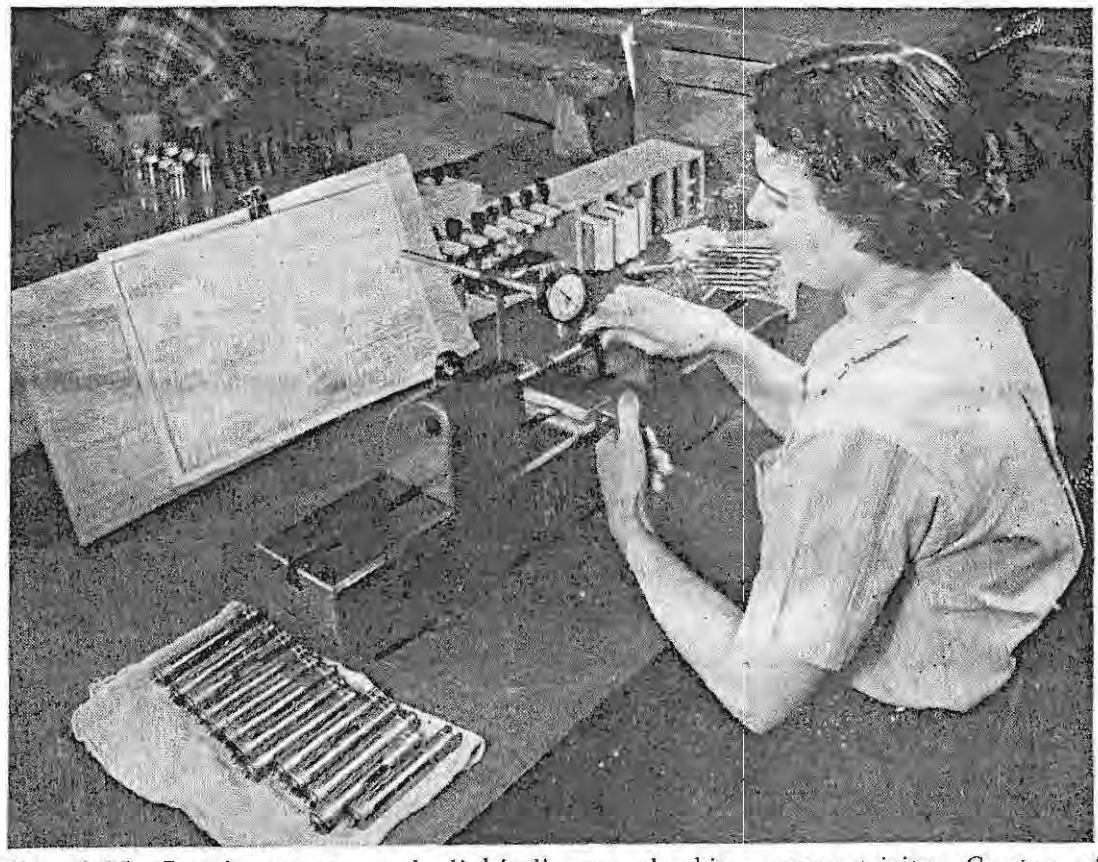


Fig. 5.25 Bench centers and dial-indicator checking concentricity. *Courtesy of Sundstrand Machine Co.*

Center Gage

A center gage, shown in Fig. 5.26, has 60-deg angular notches in a side and one end, a 60-deg point on the other end, graduated

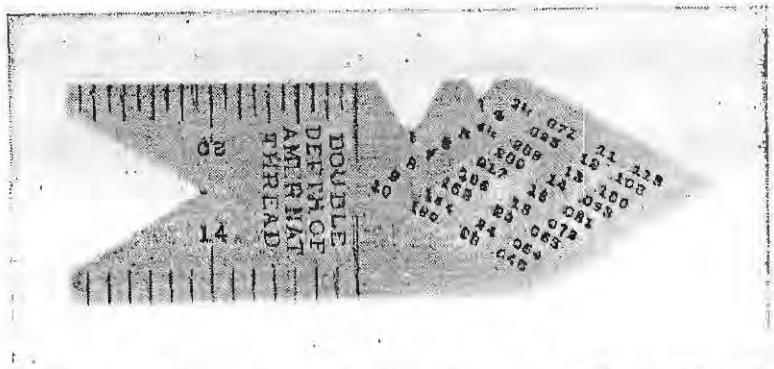


Fig. 5.26 Center gage. *Courtesy of Brown & Sharpe Mfg. Co.*

edges, and a table giving the double depths of commonly used American National Standard screw threads. The angles are useful in setting up tools to cut threads, the graduations for measuring the number of threads per inch, and the table for determining the sizes of tap drills.

Miscellaneous Gages

A screw-pitch gage is made up of a number of blades, notched on their edges with teeth of various screw-thread pitches, which are hinged on screws in the ends of a steel case. Tools are made with notches shaped to fit the various forms of screw thread in common use, and they are used to check numbers of threads per inch on screws and in nuts.

A thickness or "feeler" gage consists of several blades of thin steel, graduated in thousandths of an inch, which are hinged on a screw in the end of a steel case. Various combinations of blade thicknesses are found in different models of the tool. One model, for example, has 26 blades as follows: 0.0015 to 0.0025 in. by half-thousandths and 0.003 to 0.025 in. by thousandths. This tool is used to test close clearances between machined surfaces by inserting single blades, or combinations of blades, in the space being checked until the correct size is found. Thickness gage stock in 12-in. lengths of various thicknesses is also available.

Gages for measuring sheet metals, wire, screws, drills, and taps are made of sheet steel about $\frac{1}{16}$ in. thick. Sheet metal and wire gages have notches in their edges corresponding in size to the gage numbers to be measured, and twist drill and tap gages have round holes corresponding to the drill or tap sizes to be checked.

QUESTIONS

1. What tool may be used directly for nonprecision linear measurements. Give its technical name and its "shop" name.
2. Describe the standard No. 4 system of graduating the tool that you named in (1).

3. What nonprecision tool is used to measure the diameter of (*a*) a shaft and (*b*) a hole?

4. Name four tools that may be used for nonprecision measurement of angles.

5. Describe a nonprecision test for the squareness of adjustable and solid squares.

6. Name the tools that may be made up from a combination set.

7. What tool is used to provide a horizontal reference surface when one is required for inspection operations?

8. What tool is used in conjunction with that in (7) to provide a vertical reference surface?

6

PRECISION LINEAR MEASURING TOOLS

Micrometers

Precision linear measuring tools are instruments that will measure to known thousandths, ten-thousandths, or smaller decimal divisions of an inch. The tool most commonly used for measurements of this accuracy is the micrometer caliper. A micrometer caliper that measures to thousandths of an inch is based on the principle that an accurate screw with a graduated head will measure to thousandths provided the number of threads per inch on the screw times the number of graduations on the head equals one thousand. This principle is applied in the construction of the outside micrometer caliper, inside micrometer caliper, micrometer depth gage, bench micrometer, Supermicrometer, and Standard Measuring Machine.

Measurements by Thousandths of an Inch

Outside Micrometer Caliper

A sectional view of an 0- to 1-in. outside micrometer caliper is shown in Fig. 6.1. The principal parts of the tool are the frame, anvil, integral spindle and screw, barrel, thimble, and ratchet stop. A table of decimal equivalents is stamped on the frame of some

models and on the thimble of others. The screw may be adjusted longitudinally by turning it in a nut within the barrel to vary the distance between the measuring faces on the spindle and anvil, and the distance may be determined by reading graduations on the barrel and thimble.

The screw of an English-measure micrometer usually has 40 threads per inch. Therefore, the lead of the screw; that is, the distance that the screw moves longitudinally while making exactly one turn in the nut is $\frac{1}{40}$ or 0.025 in. Consequently, one revolution

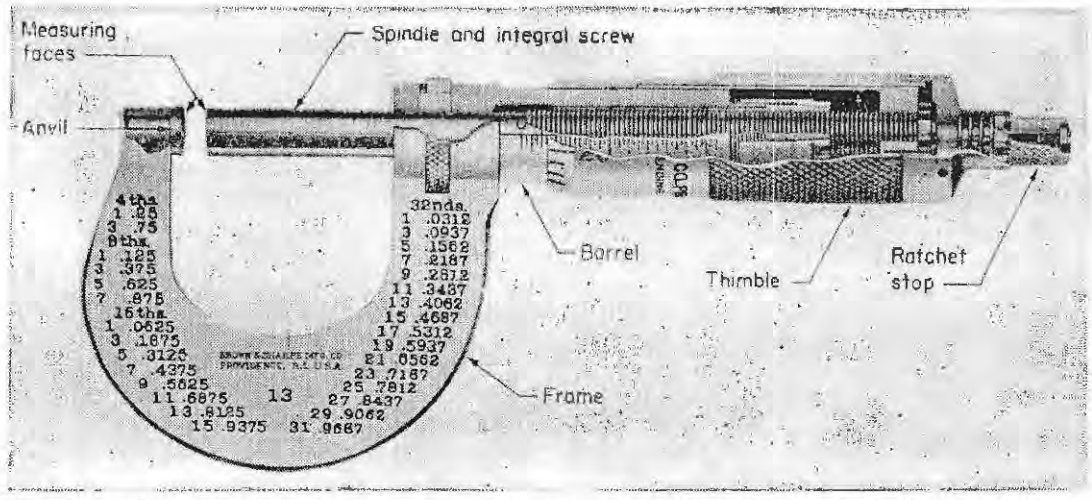


Fig. 6.1 Section view of an outside micrometer caliper. *Courtesy of Brown & Sharpe Mfg. Co.*

of the screw moves the measuring face of the spindle a distance of 0.025 in. relative to the measuring face of the anvil.

The thimble, which is attached to and turns with the spindle, is graduated with 25 equal divisions on its beveled end. Turning the screw $\frac{1}{25}$ of a revolution, as indicated by a movement from one of these graduations to the next, moves the spindle $\frac{1}{25}$ of 0.025 in. = 0.001 in. Every fifth graduation on the end of the thimble is marked in the series 0, 5, 10, 15, 20, and back to 0, to facilitate reading the instrument.

The barrel is marked with a longitudinal line, and one inch of its length is graduated with 40 divisions. The number of divisions on the barrel, therefore, is equal to the number of threads per inch on the screw; and the length of each division is 0.025 in. Every

fourth graduation extends above the longitudinal line and is marked in the series 0, 1, 2, . . . 9, 0 to assist in reading the tool. The length of four divisions on the barrel is 4×0.025 in. $= 0.100$ in. Therefore, the marked divisions should be read as 0.100 in., 0.200 in., etc.

When the measuring faces of the anvil and spindle are in contact, the beveled edge of the thimble coincides with the 0 line on the barrel, and the 0 line on the thimble coincides with the longitudinal line on the barrel if the tool is in proper adjustment. The reading of the tool at this setting is 0.

Reading the micrometer

Reading an outside micrometer caliper may be accomplished in a series of steps involving mental addition:

1. Read the highest numbered line that is seen on the barrel between 0 and the edge of the thimble. Recall that it is to be read as 0, 0.100 in., 0.200 in., etc.
2. Read the distance between the line read in (1) and the edge of the thimble. Remember that there are four divisions in each 0.100 in. and that the length of each division is 0.025 in. Therefore, the distance is read as 0, 0.025 in., 0.050 in., or 0.075 in., depending on the number of lines that are seen.
3. Read the number of the line on the edge of the thimble that coincides with the longitudinal line on the barrel. Read this as thousandths of an inch.
4. Add the individual readings in (1), (2), and (3) to find their sum. The reading illustrated in Fig. 6.2 is:

Step 1	0.200 in.	
Step 2	0.025 in.	
Step 3	0.016 in.	
Step 4	0.241 in.	*Ans.*

The commonest error in reading a micrometer is to mistake the number of divisions or lines seen in Step 2. Be careful to avoid this.

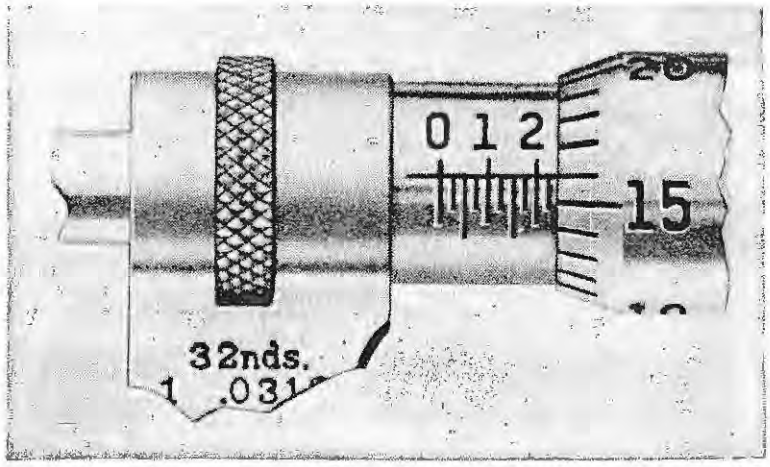


Fig. 6.2 Reading a micrometer graduated to measure by thousandths of an inch. *Courtesy of Brown & Sharpe Mfg. Co.*

Holding the outside micrometer caliper

The outside micrometer caliper should be held in the most convenient way to measure any given job. The smaller tools are often held and adjusted with one hand as seen in Fig. 6.3. Notice how

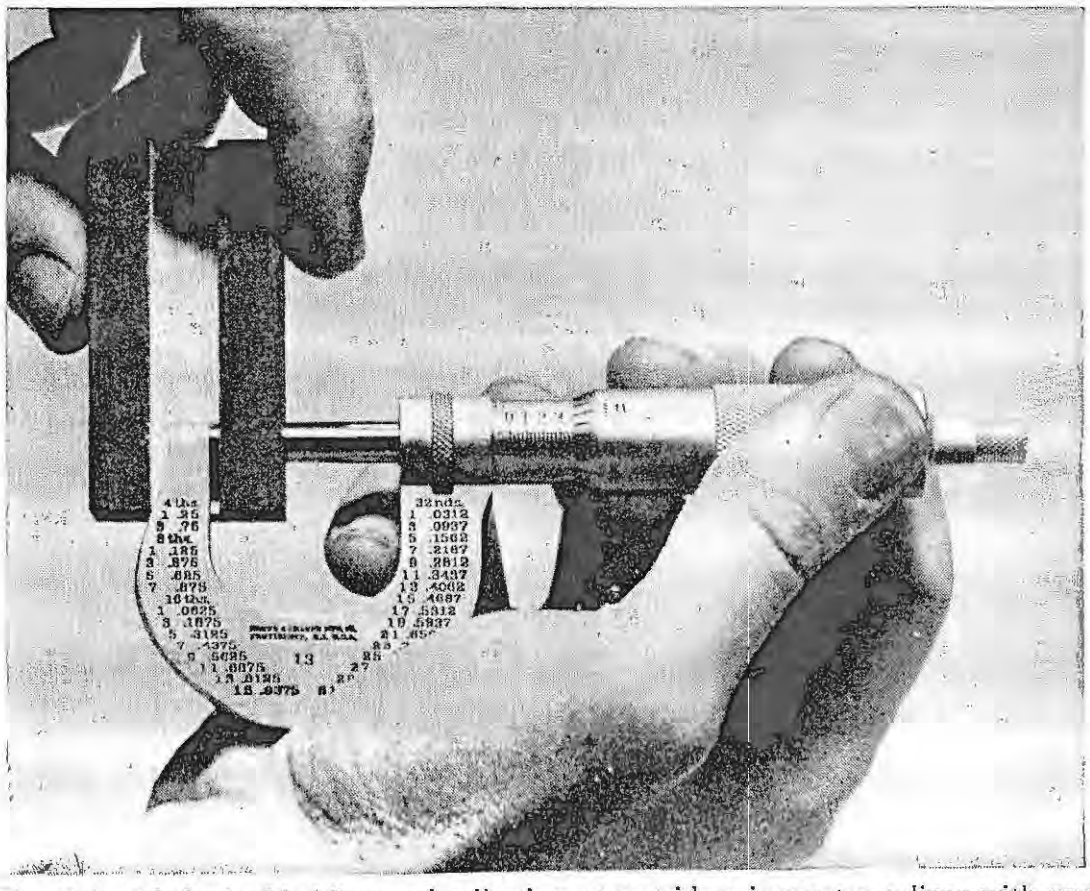


Fig. 6.3 Method of holding and adjusting an outside micrometer caliper with one hand. *Courtesy of Brown & Sharpe Mfg. Co.*

the frame of the tool is held against the palm of the hand with the little finger while the thimble is turned with the thumb and forefinger. The grip on the thimble should be very light so that the fingers will slip when the right measuring pressure is applied to the work. Two hands may be used to hold the micrometer in some instances, and a tool stand may be used to support the instrument in others.

Good measuring practices

When measuring work with an outside micrometer caliper:

1. Clean the measuring faces of the tool. To do this, insert a piece of clean, hard-surfaced paper between the measuring faces of the anvil and spindle; close the measuring faces on the paper with measuring pressure; draw about 1½ in. of the paper between them; back the spindle away from the paper; and remove the paper.
2. Clean the work.
3. Adjust the tool until the measuring faces clear the work.
4. Place the work between the anvil and spindle and turn the thimble until the measuring faces touch the work with proper measuring pressure. Be careful that the anvil and spindle make light but definite contact with the work. Be careful, also, to avoid springing the frame by applying too much force when doing this. The ratchet stop provides a means of applying correct measuring pressure; but when the micrometer is not provided with a ratchet stop, the user must depend on his sense of touch to do this. He should develop this sense through practice and use.
5. Read the tool for dimension.
6. Back the spindle away from the work and remove the work from the micrometer. This practice will avoid springing the frame and prevent unnecessary wear on the measuring faces of the tool.
7. Be sure to measure the diameter of cylindrical work, or to measure perpendicularly to flat reference surfaces, and not at an angle to them.

Micrometer features

Outside micrometer calipers are made in sizes that measure over the ranges: 0 to ½ in., 0 to 1 in., 1 to 2 in., . . . 23 to 24 in. They are sold singly and in sets covering various ranges. A standard for checking the tool is furnished with each micrometer measuring above the 0- to 1-in. range. A type of outside micrometer caliper that measures over a range of greater than 1 in. by using a set of interchangeable anvils with a single frame is available. Carbide measuring faces on some micrometers provide for long wear at these points. Frames and contact surfaces are shaped to adapt various models for measuring tubes, screw threads, paper, narrow grooves, and for heavy duty in shop and millwork.

Micrometer heads, *i.e.*, units consisting of a micrometer spindle, barrel, and thimble, are available for use in constructing special measuring tools.

Indirect applications of outside micrometer calipers

An outside micrometer is designed, of course, for making external measurements, but it may be used for internal measurements also. For example, it may be used to measure an inside caliper that has been set to the diameter of a hole. Other tools that may be used with an outside micrometer caliper for obtaining internal measurements are telescoping gages, small-hole gages, taper parallel gages, and the planer and shaper gage.

A set of telescoping gages is illustrated in Fig. 6.4. This gage consists of two spring-loaded plungers, one of which telescopes within the other, a handle, and a locking screw. To measure the diameter of a hole with a telescoping gage (*a*) lock the plungers at a size smaller than the hole; (*b*) insert the gage in the hole and release the plungers; (*c*) use one plunger as a pivot and oscillate the tool to locate the diameter of the hole; (*d*) lock the plungers; (*e*) check the "feel" of the plungers in the hole; (*f*) withdraw the gage from the hole; and (*g*) measure the gage setting with an outside micrometer caliper. The range of the five gages in the set shown is ½ to 6 in.

Small-hole gages, illustrated in Fig. 6.5, are designed for measur-

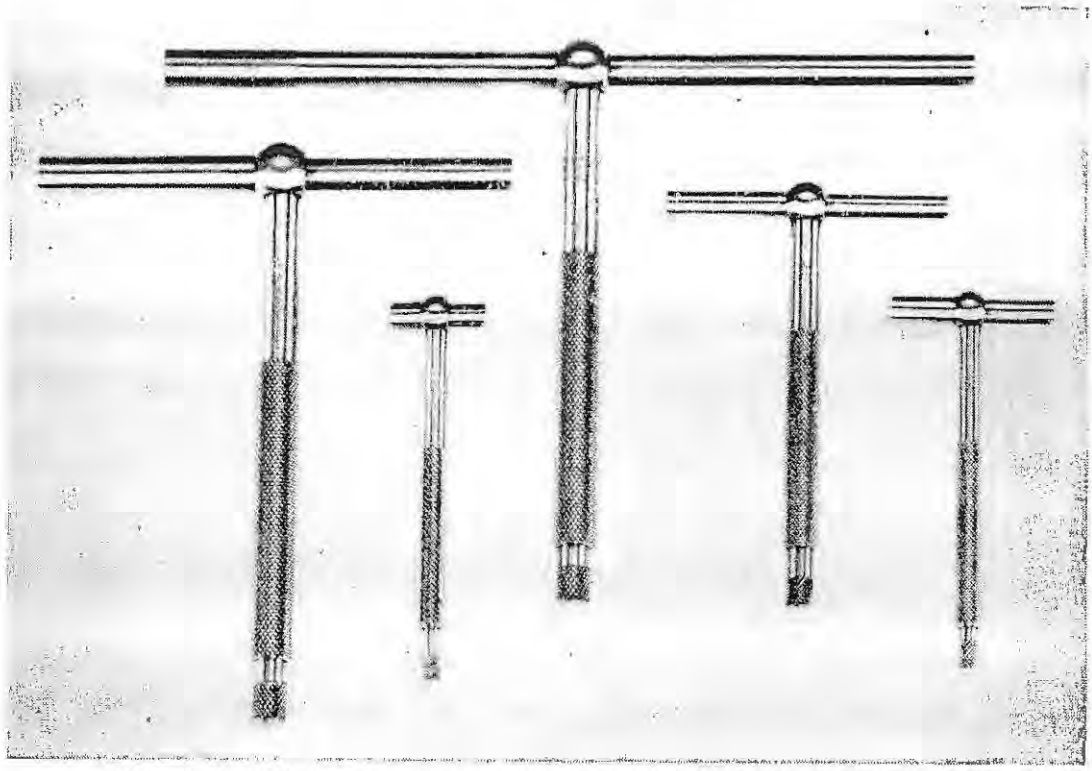


Fig. 6.4 Telescoping gages. *Courtesy of The L. S. Starrett Company.*

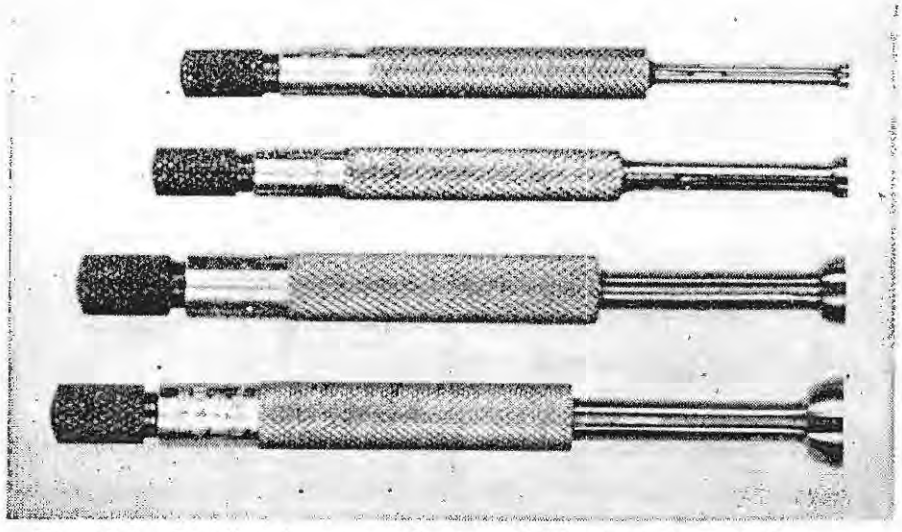


Fig. 6.5 Small-hole gages. *Courtesy of The L. S. Starrett Company.*

ing small-diameter holes or recesses in a manner similar to that described in the preceding paragraph. Turning the knurled knob at the end of the handle expands or contracts the measuring surfaces on the opposite end. The four gages in this set have a measuring range of $\frac{1}{8}$ to $\frac{1}{2}$ in.

A set of taper parallel gages consists of ten gaging pieces that have a radius ground on one edge and a tapered surface on the opposite edge. A hole may be measured by inserting two gaging pieces in the opening with their tapered edges together. Then the tapered surfaces are slid on each other so that pieces will span the hole. After this has been done, the distance across the gage is measured with an outside micrometer caliper, as shown in Fig. 6.6, to determine the

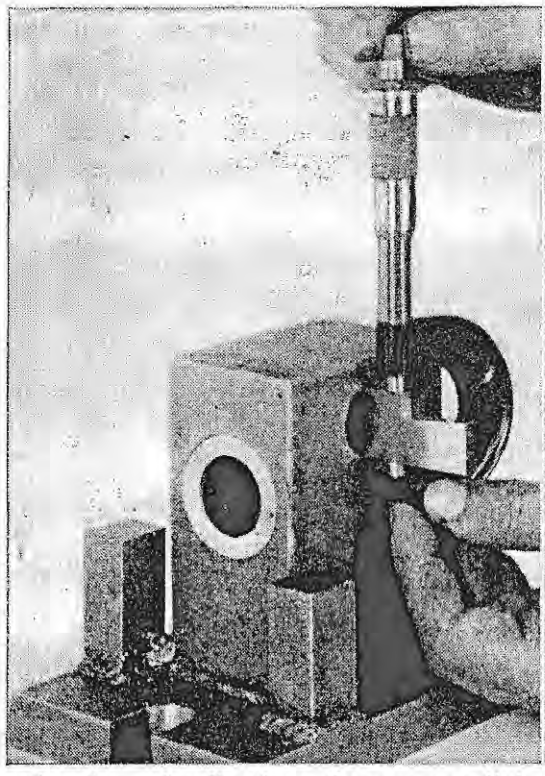


Fig. 6.6 Application of taper parallel gages. *Courtesy of Brown & Sharpe Mfg. Co.*

Fig. 6.7 Setting a planer and shaper gage with a micrometer. *Courtesy of Brown & Sharpe Mfg. Co.*

diameter of the hole. A set of these gages will measure distances from ¼ to 1 in.

A planer and shaper gage consists of three principal parts: a base with one angular edge, a slide that may be adjusted along the angular edge, and an extension which may be attached to the slide in three different positions. The gage may be used to measure distances from a reference surface over a range of ¼ to 9 in., and the setting may be measured with an outside micrometer caliper as shown in Fig. 6.7.

Testing and adjusting an outside micrometer caliper

A micrometer that is in constant service should be checked for wear regularly. A 0- to 1-in. outside micrometer caliper should be checked by cleaning its measuring faces, closing the measuring faces on each other with the correct measuring pressure, and reading the tool. If the tool does not read zero, it needs adjustment. Adjustments on different makes of micrometers vary; therefore, the manufacturer's instructions for doing this work should be secured and followed. Tools larger than 0 to 1 in. should be checked in the same manner by measuring the standards of the required lengths which are furnished with them.

The lead accuracy of an outside micrometer caliper may be determined by measuring precision gage blocks of different lengths within its size range.

Flatness and parallelism of the measuring faces on an outside micrometer caliper may be tested with one or more optical parallels. These tools, and precision gage blocks, are described in Chap. 7.

Care of Micrometers

A micrometer caliper is a precision tool, and it should be cared for accordingly. Do not lay a micrometer on a dirty tool tray or work bench. Do not lay a micrometer among other tools in a tool tray or box. Do not drop a micrometer. Do not close a micrometer with so much pressure as to spring the frame. Do not attempt to measure moving work with a micrometer. Do not spin the frame on the screw to open or close the tool rapidly. Do not take the tool apart unnecessarily. Clean work before measuring it. Clean the tool after use and wipe it with a rust preventive before putting it away. Do not put it away, however, with the measuring faces closed on each other.

Inside Micrometer Calipers

Inside micrometer calipers are used to measure internal dimensions of holes, slots, and similar forms of construction. This tool is made in two principal types: a jaw type and a measuring-rod type.

Jaw-type Inside Micrometer Caliper

A jaw-type inside micrometer caliper is illustrated in Fig. 6.8. The principal parts of the tool are a spindle with a jaw fixed on its end, and a barrel with a second jaw fixed on its end, and a thimble. Measuring surfaces or nibs are formed on the jaws to permit their entry into the smallest hole that the tool will measure. One model of the micrometer measures over the range of 0.200 to 1.000 in., and another model measures over the range of 0.500 to 1.500 in. The

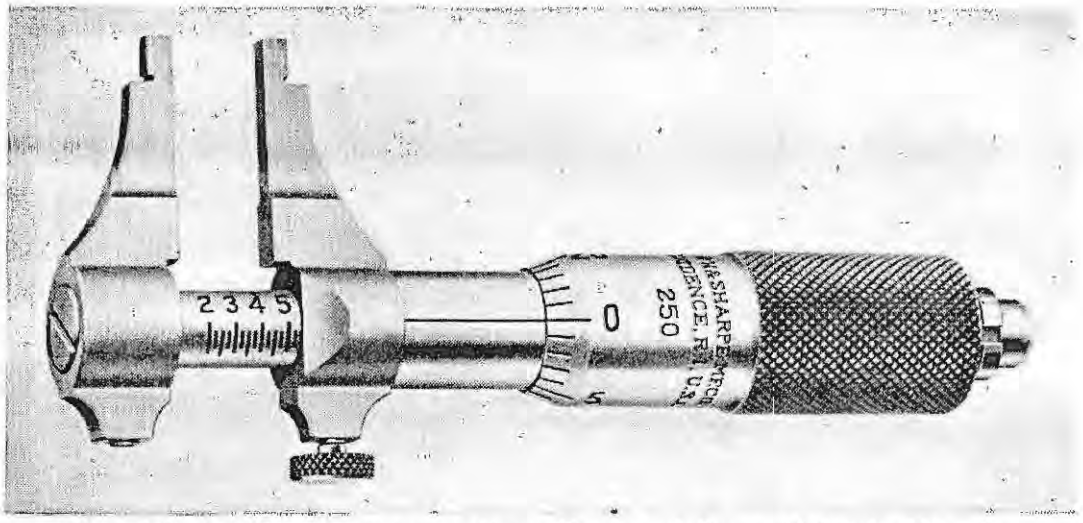


Fig. 6.8 Inside micrometer caliper. *Courtesy of Brown & Sharpe Mfg. Co.*

Brown and Sharpe jaw-type inside micrometer caliper, shown in Fig. 6.8, has the graduations that represent whole turns of the screw marked on the spindle, and the tool is read in much the same manner as described previously for an outside micrometer caliper. The Starrett jaw-type inside micrometer caliper has these graduations on the barrel with the smallest dimensions at the right end; therefore, the graduations that are read are those which are covered by the thimble. This is the same construction that is illustrated in Fig. 6.10, which shows a micrometer depth gage.

To measure a hole with a jaw-type inside micrometer caliper:

1. Clean the work.
2. Adjust the tool so that its nibs will enter the hole.
3. Insert the nibs in the hole and adjust the tool until the measuring surfaces touch the work with the proper measuring

pressure. This tool is not as rigid as an outside micrometer caliper; therefore, more care must be used to avoid springing it than is necessary with that type.

4. Read the tool in place if possible.
5. Close the jaws slightly and remove the tool from the work.
6. If the micrometer cannot be read in place, clamp the spindle and remove the tool from the work to read it. Be careful to avoid springing the tool during the removal operation.

Measuring-rod-type Inside Micrometer Caliper

A measuring-rod-type inside micrometer caliper is shown in Fig. 6.9. The details of this tool will vary slightly with the make and

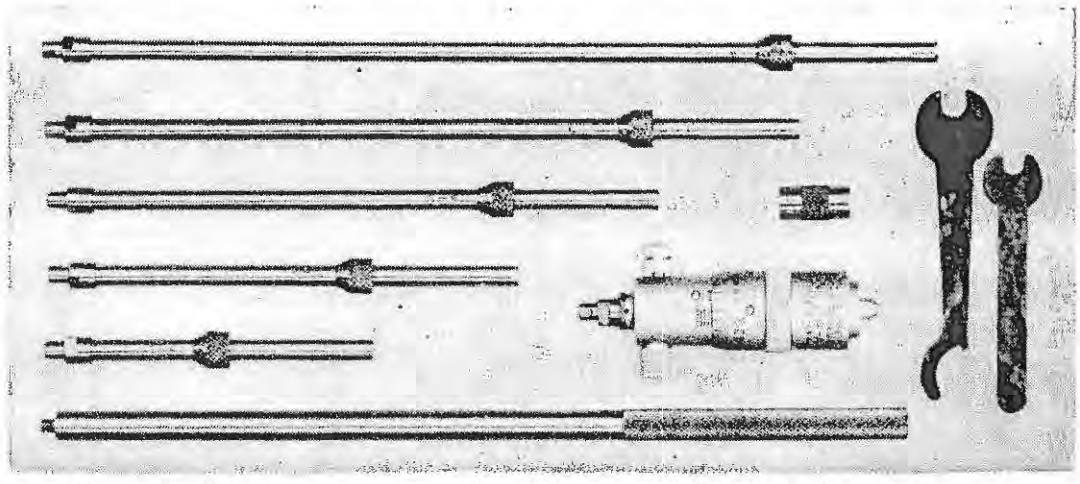


Fig. 6.9 Inside micrometer caliper. *Courtesy of The L. S. Starrett Company.*

model under consideration. A typical tool consists of a micrometer head with a screw that has ½-in. movement, a set of interchangeable measuring rods that differ in length by 1 in., a ½-in. spacing collar that permits each rod to be used in either of two positions, and a lock screw to fasten the measuring rods in the micrometer head. Each measuring rod is marked with the range of sizes that may be measured when that particular rod is used. The total range of a given tool depends on the micrometer head and the rods that make up the instrument. The minimum size that may be measured with different tools in common use is 1, 1½, and 2 in., according to make and model; and the maximum size may range upward to 32 in. or more. Some tools are furnished with tubular members instead

of rods to secure lightness and rigidity, and some are provided with handles to permit their use in measuring deep holes and slots.

To measure a hole with a measuring-rod-type inside micrometer:

1. Clean the work.
2. Measure the hole with a steel rule to determine its approximate size and the size of the measuring rod that must be used.
3. Clean and assemble the required measuring rod, the sleeve, if it is needed, and the micrometer head.
4. Position the rod end of the tool in the hole and support it in place with one hand. Use this end as a pivot on which the tool is oscillated while performing (5).
5. Position and adjust the head end of the tool with the other hand so that it measures the diameter of the hole. Positioning the tool consists of moving the head end in longitudinal and transverse arcs to determine, by feel, when the diameter is located.
6. Read the tool in place if possible. If not, withdraw the tool from the hole without performing (7).
7. Close the tool slightly and remove it from the hole.

To illustrate the choice of a measuring rod to measure a particular hole: assume that the range of the measuring-rod-type inside micrometer caliper to be used is 2 to 8 in., that there are six measuring rods which are marked 2–3, 3–4, . . . and 7–8, and that there is a ½-in. spacing collar with the tool. Assume also that the scaled diameter of the hole to be measured is 3⅞ or 3.875 in. This is between 3½ and 4 in.; therefore, the 3–4 measuring rod and the ½-in. spacing collar are assembled with the micrometer head so that the tool will measure over the range 3½ to 4 in. At this point, the tool should be checked with an outside micrometer caliper to be sure that it is assembled and adjusted properly. If the tool is checked at the nominal size of 3.875 in., the reading on the inside micrometer head should be 3.875 in. − 3.500 in. = 0.375 in. Finally, assume that the work is actually 3.878 in. in diameter. The micrometer reading of this dimension will be made up as follows:

Mark on measuring rod 3–4	3.000 in.	
Length of spacing collar	0.500 in.	
First reading on barrel	0.300 in.	
Second reading on barrel	0.075 in.	
Reading on thimble	0.003 in.	
Total reading	3.878 in.	*Ans.*

Micrometer Depth Gage

A micrometer depth gage (Fig. 6.10) consists of a micrometer head, a rectangular base attached to the barrel of the tool, and a

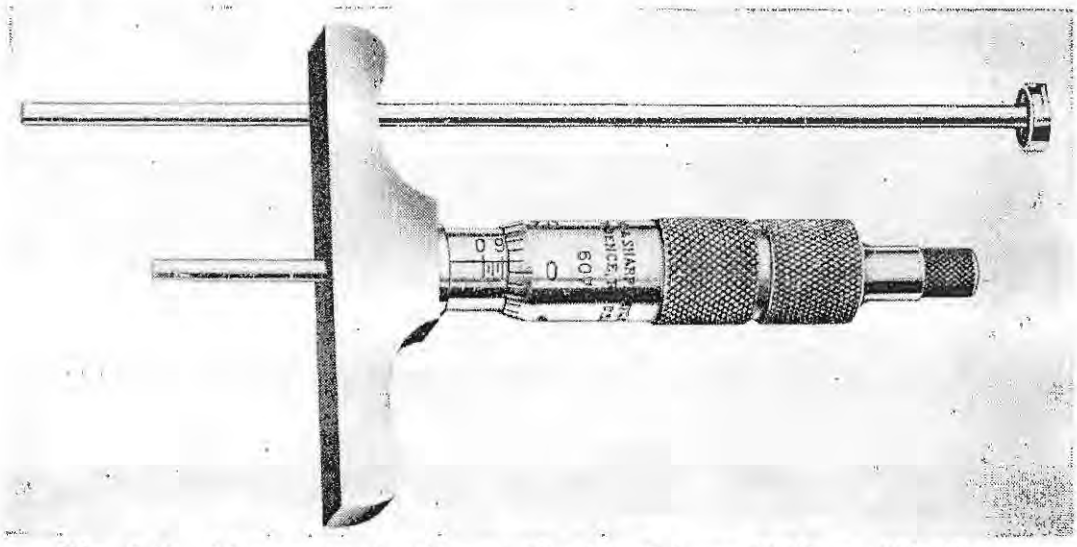


Fig. 6.10 Micrometer depth gage *Courtesy of Brown & Sharpe Mfg. Co.*

set of interchangeable measuring rods that are inserted through a hole in the micrometer head to project beyond the base for measuring depths of holes, slots, etc. The micrometer screw has a movement of 1 in., and the measuring rods differ in length by 1 in. Therefore, the tool has a capacity of 0 to 1 in. with the shortest rod in place, and up to the capacity provided by the longest rod with the others. All parts of the tool should be cleaned carefully when changing from one rod to another, and it should be checked with a standard after a change has been made to be sure that it is assembled and adjusted properly.

This tool differs from most micrometers in that the graduations on the barrel, which represent turns of the screw, are marked 0, 9, 8, . . . 0 instead of in the usual reverse order. Therefore, the

graduations that are covered by the thimble must be counted when reading this tool.

Verniers

A vernier is an auxilliary scale that is moved along the regular scale of a measuring tool to indicate parts of divisions on the regular scale. The usual arrangement of scales for reading English measurements to thousandths of an inch is illustrated in Fig. 6.11. The reg-

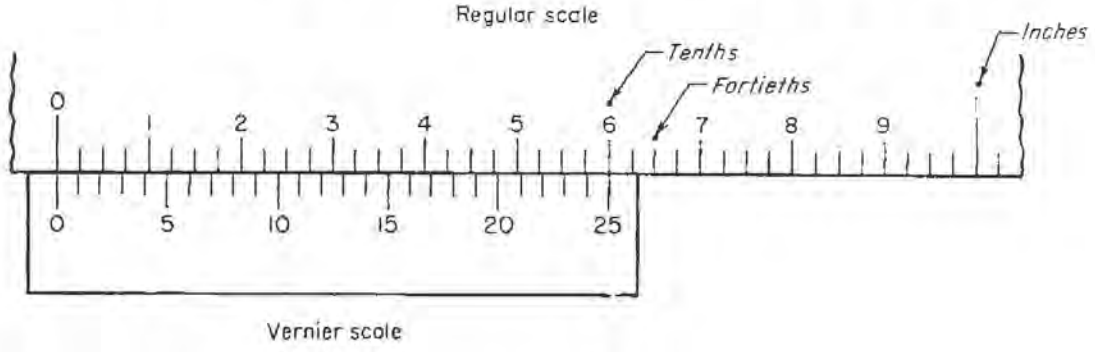


Fig. 6.11 Regular and vernier scales.

ular scale is divided in inches, tenths, and fortieths. Tenths are numbered in the series 0, 1, 2, . . . , 0 and are read as hundred thousandths of an inch; and fortieths are read as twenty-five thousandths of an inch. The vernier scale is 0.600 in. long and is divided into 25 equal parts; each fifth division is numbered in the series 0, 5, 10, . . . , 25. There are 24 fortieths in 0.600 in. on the regular scale; therefore, the length of a regular scale division is

$$0.600 \text{ in.} \div 24 = 0.025 \text{ in.}$$

But there are 25 divisions in 0.600 in. on the vernier scale; therefore, the length of a vernier scale division is

$$0.600 \text{ in.} \div 25 = 0.024 \text{ in.}$$

That is, a vernier scale division is 0.025 in. − 0.024 in. = 0.001 in. shorter than a regular scale division. With the scales set at zero, as in Fig. 6.11, the first graduation on the regular scale is 0.001 in. to the right of the first division on the vernier scale. Moving the vernier 0.001 in. to the right will cause the first graduations on the two

scales to coincide, and they will be the only two lines on the scales that do agree. The reading of the tool in this position is 0.001 in. Moving the vernier another 0.001 in. to the right will cause the second lines on the scales to coincide, and the reading of the tool will be 0.002 in. Further movement of the vernier to the right will cause successive graduations to coincide until, after a movement of 0.025 in. the zero line on the vernier will agree with the 0.025 in. line on the regular scale. After this point has been reached, further movement of the vernier will repeat the cycle so that measurements in thousandths of an inch may be made throughout the full range of the tool.

To read a vernier caliper and similar tools:

1. Read the number of whole inches on the regular scale that appear to the left of 0 on the vernier.
2. Read the highest numbered graduation on the regular scale that lies between the inch mark read in (1) and 0 on the vernier. Recall that these numbered graduations are read as 0.100 in., 0.200 in., etc.
3. Read the number of fortieths on the regular scale that lie between the "tenth" read in (2) and 0 on the vernier. These divisions are read as 0, 0.025 in., 0.050 in., or 0.075 in.
4. Locate the graduation on the vernier that coincides with a graduation on the regular scale. The number of divisions on the vernier between 0 and the coincident line is read as thousandths of an inch.
5. The sum of these readings is the dimension that the tool is set to measure.

The reading illustrated in Fig. 6.12 is

Step 1	2.000 in.	
Step 2	0.300 in.	
Step 3	0.050 in.	
Step 4	0.018 in.	
Step 5	2.368 in.	*Ans.*

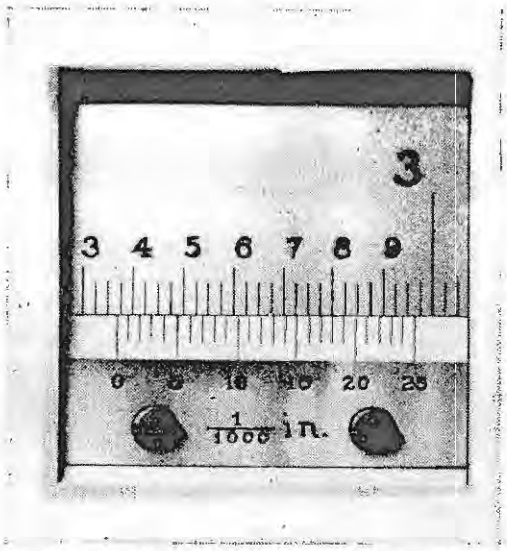


Fig. 6.12 Vernier reading. *Courtesy of Brown & Sharpe Mfg. Co.*

Vernier calipers

A vernier caliper (Fig. 6.13) consists of a beam and a fixed jaw, a movable jaw, and a screw, nut, and nut carrier for fine adjustments of the movable jaw. Locking screws on the movable jaw and nut carrier are used to fasten these members in place on the beam as required. The jaws are finished with nibs on their outer ends so that

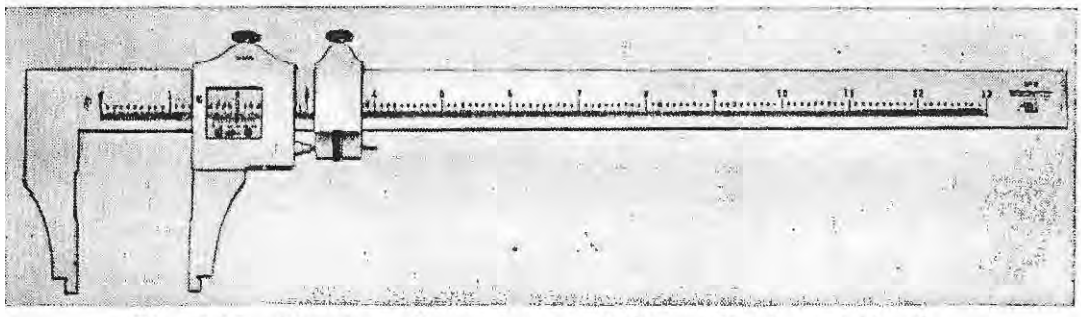


Fig. 6.13 Vernier caliper. *Courtesy of Brown & Sharpe Mfg. Co.*

the tool may be used to make either outside or inside measurements. The beam is graduated with a regular scale for outside measurements on one side and for inside measurements on the other side, and vernier plates on opposite sides of the movable jaw permit either outside or inside measurements to be read without having to compensate for the thickness of the nibs. To measure with a vernier caliper:

1. Clean the work.
2. Loosen the locking screws on the movable jaw and nut carrier.
3. Set the tool to the approximate size of the work.
4. Lock the nut carrier in place on the beam.
5. Turn the adjusting nut to set the movable jaw so that it just touches the work.
6. Lock the movable jaw in place on the beam.
7. Check the setting of the tool.
8. Read the graduations.
9. Loosen the locking screws, slide the movable jaw and nut carrier away from the work, and move the tool away from the job.

Be careful to avoid springing the tool if, to read the graduations, it is necessary to move it away from the work while the movable jaw is locked in position on the beam.

Vernier calipers are made in 6, 9, 12, 24, 36, and 48 in. sizes.

Vernier depth gage

The vernier depth gage, illustrated in Fig. 6.14, is used to measure depths of holes and slots. The tool consists of a blade that is graduated along one edge with a regular scale, a head to provide a base or reference surface for measurements, a vernier plate mounted

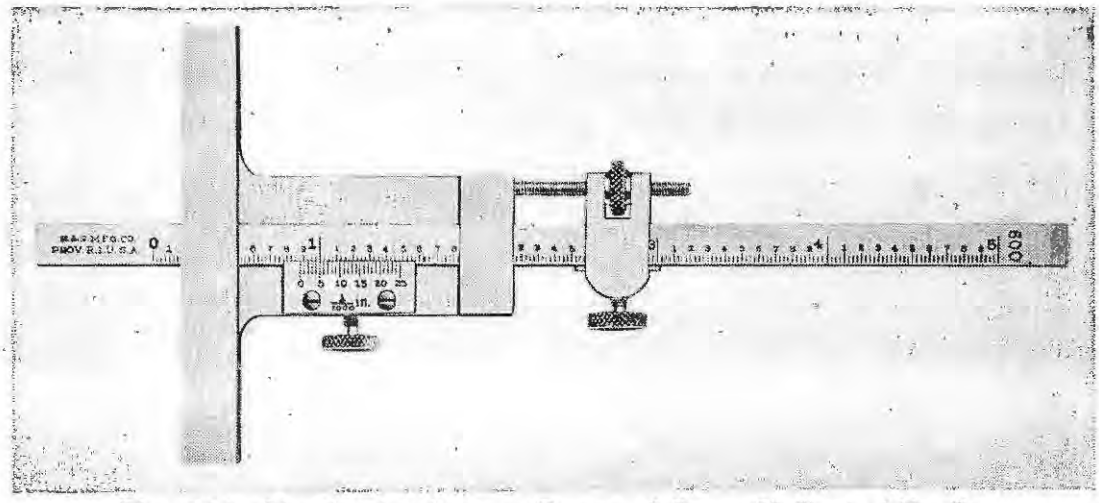


Fig. 6.14 Vernier depth gage. *Courtesy of Brown & Sharpe Mfg. Co.*

on the head, a screw, nut, and nut carrier for fine adjustments, and locking screws for the head and nut carrier.

Vernier height gage

The vernier height gage, illustrated in Fig. 6.15, may be used to measure and mark vertical distances above a reference surface, or as an outside caliper. The tool consists of an integral base and bar, a movable jaw with two vernier plates—one for height gage measurements and one for outside caliper measurements, a screw, nut, and nut carrier for fine adjustments of the movable jaw, locking screws for the movable jaw and nut carrier, and a combination marker and extension. Graduations on one side of the bar are arranged for measuring heights from the bottom of the base to the marker located on top of the movable jaw; graduations on the other side of the bar are used for outside caliper measurements. An offset marker, available for use with these tools, permits measuring and scribing lines to the bottom of the base.

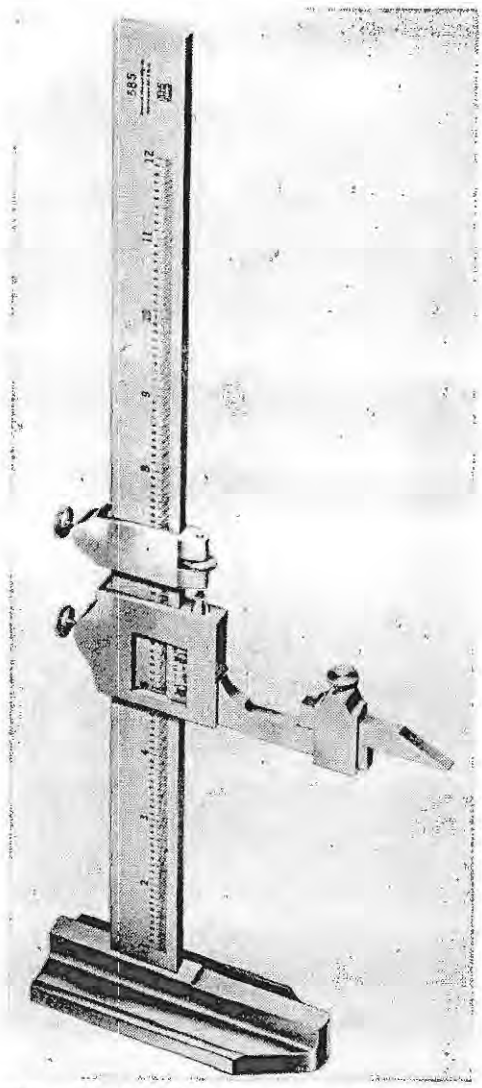


Fig. 6.15 Vernier height gage with combination marker and extension. *Courtesy of Brown & Sharpe Mfg. Co.*

A depth gage attachment for use with this tool may be used to reach over obstructions on work for measuring depths. To use this attachment:

1. Fasten the attachment to the movable jaw.
2. Set the height gage on the reference surface of the work.
3. Set the depth-gage rod so that its end is in contact with the reference surface. This may be done by adjusting the rod

itself, by adjusting the head of the tool, or by a combination of both.

4. Note the reading.
5. Set the depth-gage rod in contact with the surface whose depth is to be measured by adjusting the head of the tool only.
6. Note the reading. The difference in the two readings is the required measurement.

Vernier instruments are precision tools. They should be accorded the same care that has been described previously for tools of this class.

Measurements by Ten-thousandths of an Inch

Micrometer Graduated to Ten-thousandths of an Inch

The micrometer graduated to ten-thousandths of an inch, illustrated in Fig. 6.16, combines the principles of the micrometer

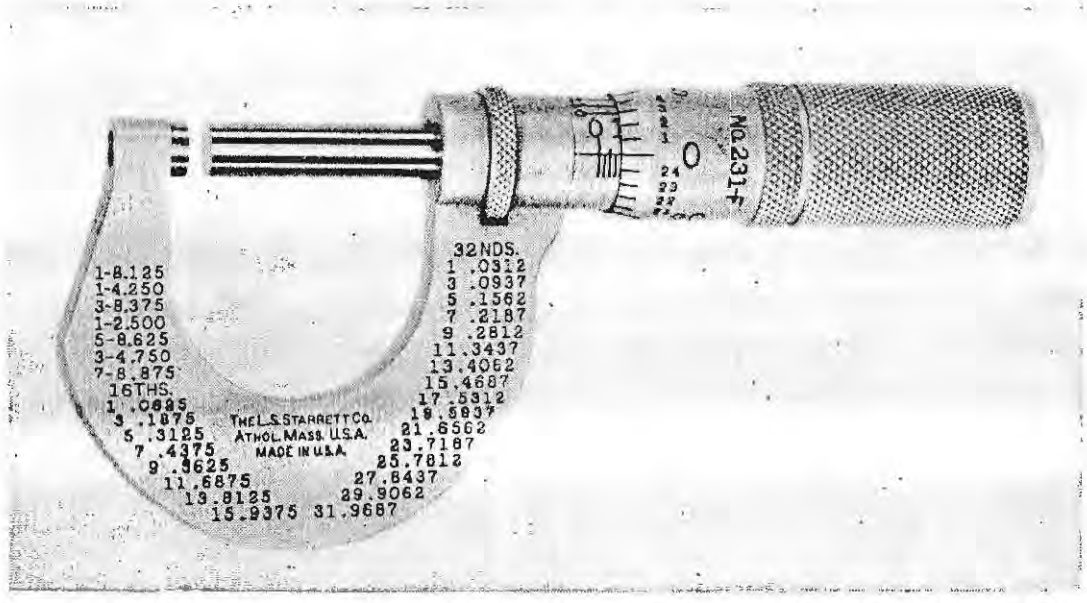


Fig. 6.16 Outside micrometer caliper with graduations reading to ten-thousandths of an inch. *Courtesy of The L. S. Starrett Company.*

and vernier in one instrument. The vernier consists of 10 graduations on top of the barrel that occupy the same space as 9 divisions on the beveled end of the thimble. To read a ten-thousandths micrometer:

1. Read thousandths of an inch in the same way as on micrometers described previously.
2. Find the line on the vernier that coincides with a line on the thimble. The number at the end of that line on the vernier is the number of ten-thousandths of an inch in the measurement.

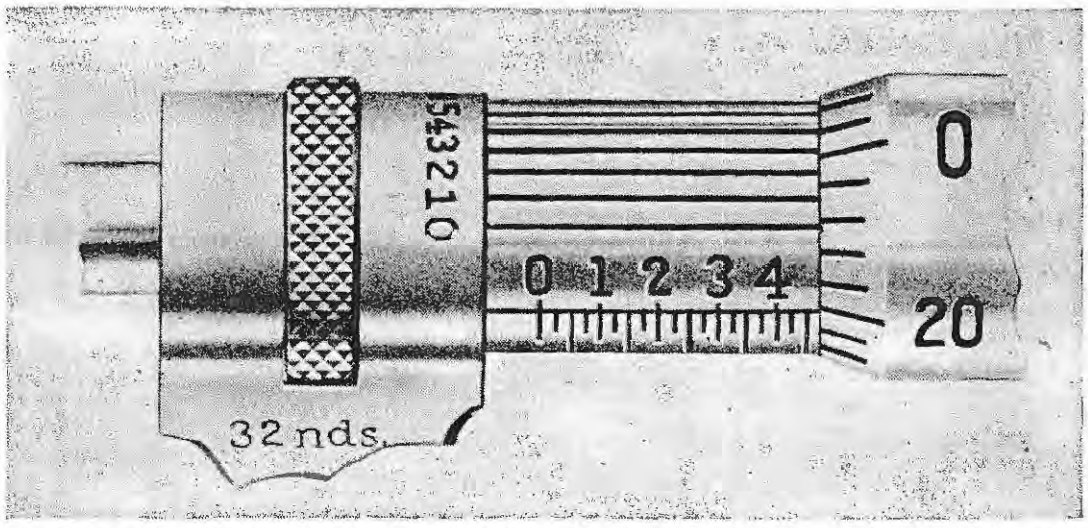


Fig. 6.17 Reading a micrometer graduated to measure by ten-thousandths of an inch. *Courtesy of Brown & Sharpe Mfg. Co.*

3. Add the readings obtained in (1) and (2). The reading illustrated in Fig. 6.17 is:

Step 1	0.4690 in.	
Step 2	0.0004 in.	
Step 3	0.4694 in.	*Ans.*

Bench Micrometer

A bench micrometer is shown in Fig. 6.18. Tools of this type are useful when one hand is needed to hold the work while the other hand operates the thimble. The tool that is illustrated has a screw with 50 threads per inch, and a thimble with 200 graduations so that measurements of ten-thousandths of an inch may be read directly on the thimble. The dial gage on this instrument, which is connected with the anvil, permits repetitive measurements at a predetermined pressure so that errors will not arise through variations in this element; and ten-thousandths graduations on the dial, and a

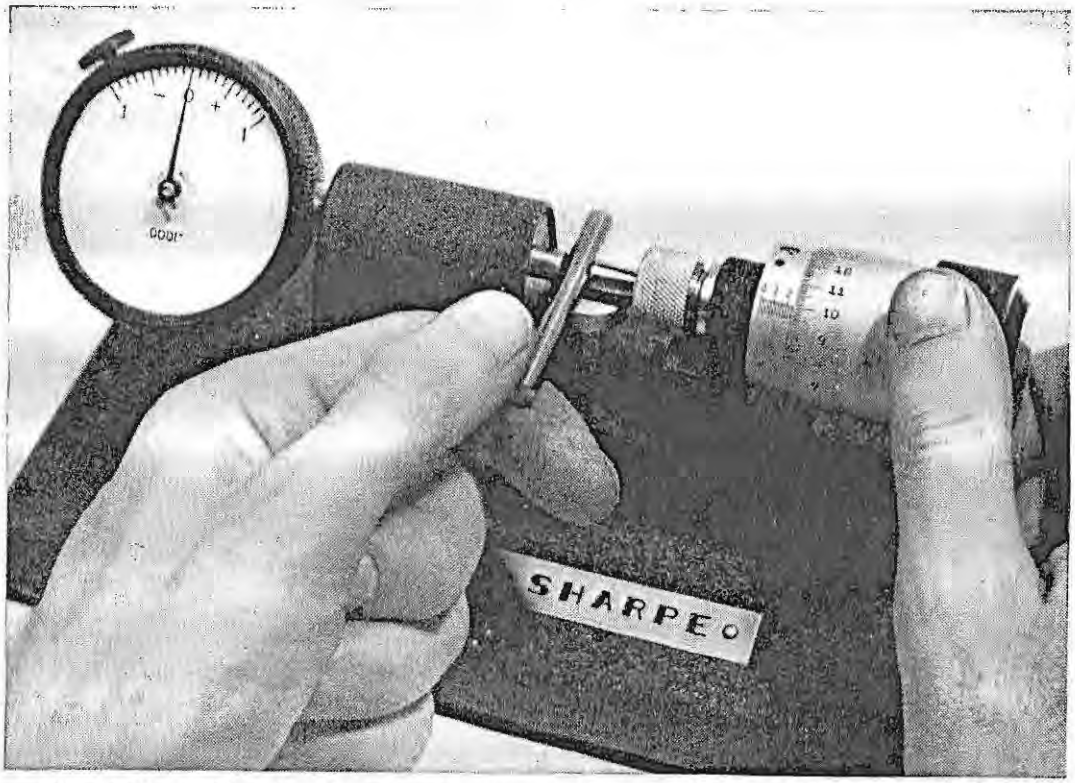


Fig. 6.18 Indicating bench micrometer. *Courtesy of Brown & Sharpe Mfg. Co.*

retractor lever to withdraw the anvil from work, adapts this tool for direct measuring or for use as a comparator.

Supermicrometer

The Supermicrometer, shown in Fig. 6.19, consists of a bed, a measuring headstock, and a pressure tailstock. Regular equipment furnished with the tool consists of an elevating table, a cast-iron lap and lapping compound, a set of Hoke precision gage blocks, and two flatted cylinders.

The bed of the Supermicrometer is a heavy, chromium-plated, hollow steel cylinder that is supported at one end by legs, which are an integral part of the headstock casting, and at the other end by a fixed support.

The headstock of the Supermicrometer contains an accurate measuring screw, a compensating bar to correct lead errors in the measuring screw, a spindle, a measuring dial, and a vernier. The measuring screw has 20 threads per inch, and the measuring dial has 50 divisions; therefore, thousandths of an inch may be read di-

rectly on the dial. The vernier, which is located beside the measuring dial, has 10 graduations that occupy the same space as 9 divisions on the dial; consequently, ten-thousandths of an inch may be read on the vernier. A horizontal line is marked on the spindle, and 1 in. of its length is graduated with 20 divisions, each one of which represents a full turn of the measuring screw. Each divi-

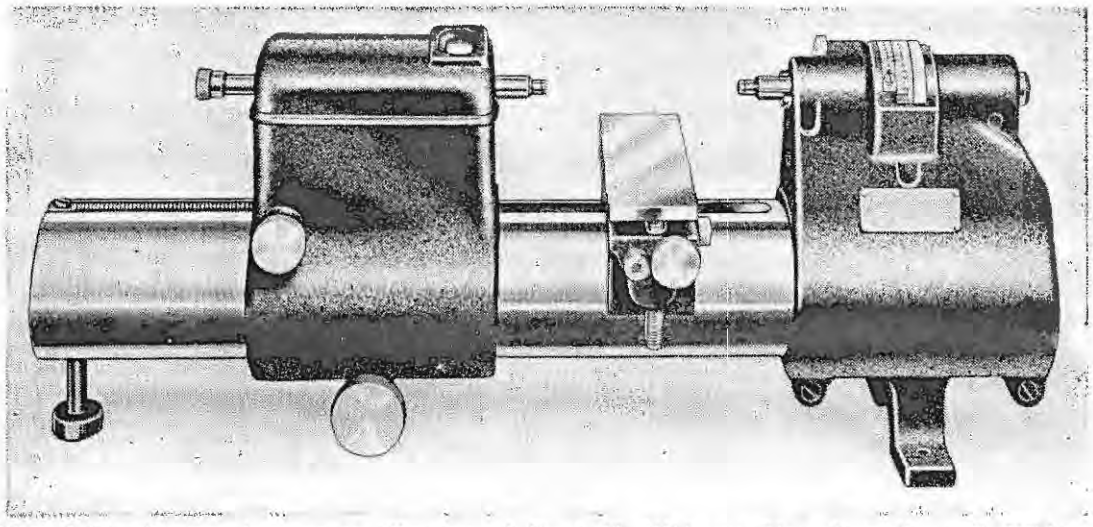


Fig. 6.19 Supermicrometer. *Courtesy of Pratt & Whitney; Photo from Pratt & Whitney Division, Niles-Bement-Pond Co.*

sion measures 0.050 in., and every second division is numbered in the series 0, 9, 8, . . . 1, 0 to facilitate reading the tool.

The pressure tailstock is adjustably mounted on the bed, and it may be positioned at 1-in. intervals along the bed to allow measurements from 0 up to 10 in. The tailstock contains an anvil that is connected with an indicating pressure device to regulate measuring pressures at either 1 or 2½ lb. These are the pressures recommended for use in measuring screw threads by the three-wire system.

The Supermicrometer should be set to measure work by following a systematic plan:

1. Center the vernier between its stops using the quadrant and pinion arrangement provided for this purpose.
2. Turn the measuring dial until the spindle is at the outer end of its travel and reads zero. Zero on the measuring dial should register with zero on the vernier also.

3. Set the pressure selecting knob on the tailstock to give 1 or 2½ lb pressure as required.
4. Move the tailstock until its anvil contacts the headstock anvil.
5. Place a piece of clean, hard-surfaced paper between the anvils and draw about 1½ in. of it between the anvils to clean them. Back the headstock spindle away from the tailstock anvil to remove the paper.
6. Move the tailstock away from the headstock to permit placement of the Hoke precision gage blocks which are used to position the tailstock on the bed. See (8) and (9).
7. Mount the elevating table on the bed between the headstock and tailstock and place one flatted cylinder on the table.
8. Select Hoke precision gage block(s) to the number of whole inches contained in the desired measurement. A measurement between 3 and 4 in., for example, requires the use of the 3-in. block. If two or more blocks are required, they may be fastened together with tie rods and screws. Clean the blocks before using them.
9. Place the gage block(s) on the flatted cylinder and raise or lower the elevating table to align it (them) with the anvils.
10. Move the tailstock until both anvils touch the gage block(s) and the indicator hand registers with the index line on the pressure regulating dial.
11. Clamp the tailstock to the bed.
12. Realign the indicator hand with the index line by adjusting the measuring dial.
13. Check the alignment of the gage block(s) by their "feel" between the anvils.
14. If the gage-block alignment is correct, realign the vernier by setting its zero to the zero on the measuring dial.
15. Back the headstock spindle away from the tailstock anvil, remove the gage block(s) and flatted cylinder, clean and coat them with a rust preventive, and store them in their case. The Supermicrometer is ready to use.

Place work to be measured on the elevating table between the anvils. Raise or lower the table to align the work with the anvils; then turn the measuring dial until the anvils are against the work, and the indicator registers with the index line on the pressure regulating dial. Read the measurement with the work in place, then back the spindle away from the work to remove it. Read the Supermicrometer by adding the Hoke precision gage-block measurement, and the spindle, measuring dial, and vernier readings.

Although the Supermicrometer is equipped with carbide-tipped anvils to provide long wear at these points, use will cause the measuring surfaces to wear hollow in time. The cast-iron lap and diamond lapping compound, furnished as regular equipment with this tool, are for restoring flatness to these surfaces. The procedure is as follows:

1. Set the headstock spindle at 0.500 in. and the measuring pressure at 2½ lb.
2. Move the tailstock up so that the lap may be inserted between the two anvils.
3. Be sure that the lap is clean. Put a small quantity of the lapping compound on both sides of the lap and insert it between the two anvils squarely.
4. Lap the anvils by using a figure-of-eight motion, utilizing the entire surface of the lap.
5. Remove the lap, clean the anvils with kerosene, and wipe dry.
6. Finally, clean the anvils with paper as described previously.

Measurements by Hundred-thousandths of an Inch

Standard Measuring Machine

The Standard Measuring Machine, illustrated in Fig. 6.20, consists of a bed, master bar, measuring head, and Electrolimit pressure tailstock.

The bed of the Standard Measuring Machine is a heavy iron casting that is seasoned naturally and then subjected to a series of stabilizing treatments between manufacturing operations to ensure

its stability and accuracy indefinitely. The bed rests on three feet to avoid distortion. Precision, hand-scraped ways provide surfaces on which the measuring head and pressure tailstock may be positioned accurately.

The seasoned-steel master bar is mounted on the rear of the bed, where it is protected with a cover when not in use. The bar has hardened, stainless-steel plugs set into it at 1-in. intervals for use in positioning the measuring head for inspection operations. Each

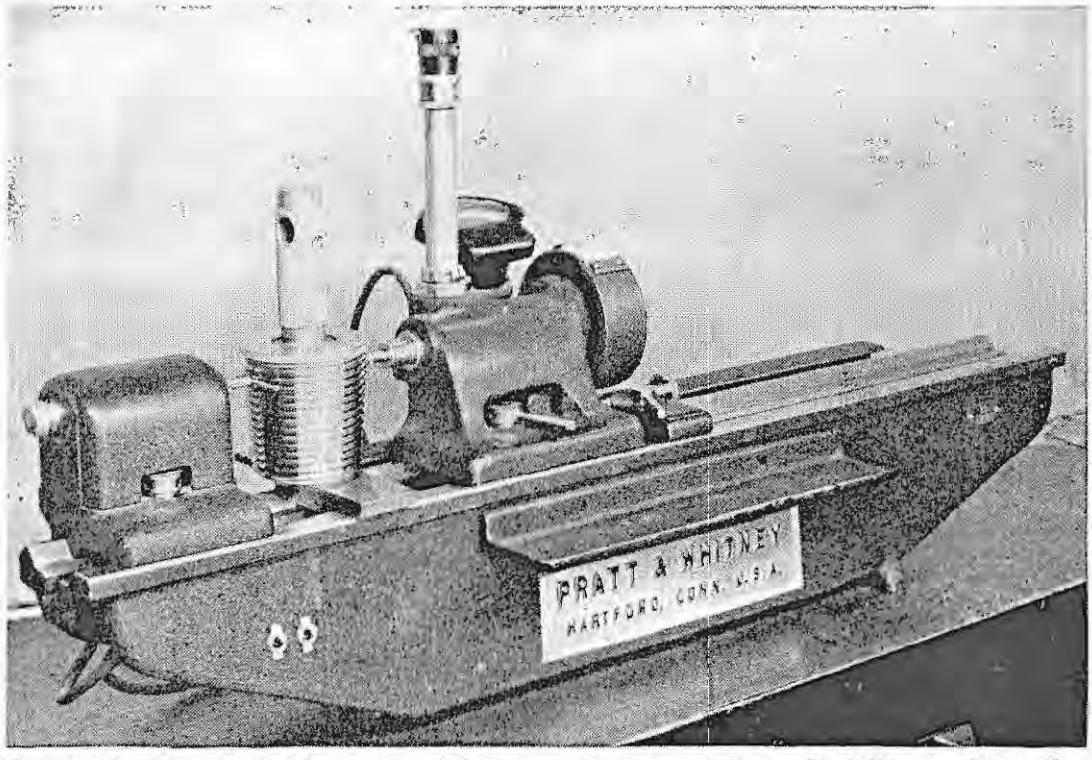


Fig. 6.20 Standard Measuring Machine. *Courtesy of Pratt & Whitney; Photo from Pratt & Whitney Division, Niles-Bement-Pond Co.*

plug has a microscopic hair line on its surface which is transferred from a master bar calibrated at the National Bureau of Standards in Washington, D.C. All measurements are referred to the master bar, and their accuracy is dependent on it.

The measuring head, shown in Fig. 6.21, contains a precision dividing screw, a lead compensator to counteract any lead errors in the screw, three measuring dials under a magnifier, a microscope and microscope lamp, and a milliammeter.

The precision measuring screw has 25 threads per inch, and the central measuring dial has 400 graduations; therefore, ten-thou-

sandths of an inch may be read directly on this dial, and hundred-thousandths of an inch may be read on the vernier beside it.

The microscope has two parallel cross lines in its eyepiece that are used to locate the measuring head relative to the index lines on the master bar.

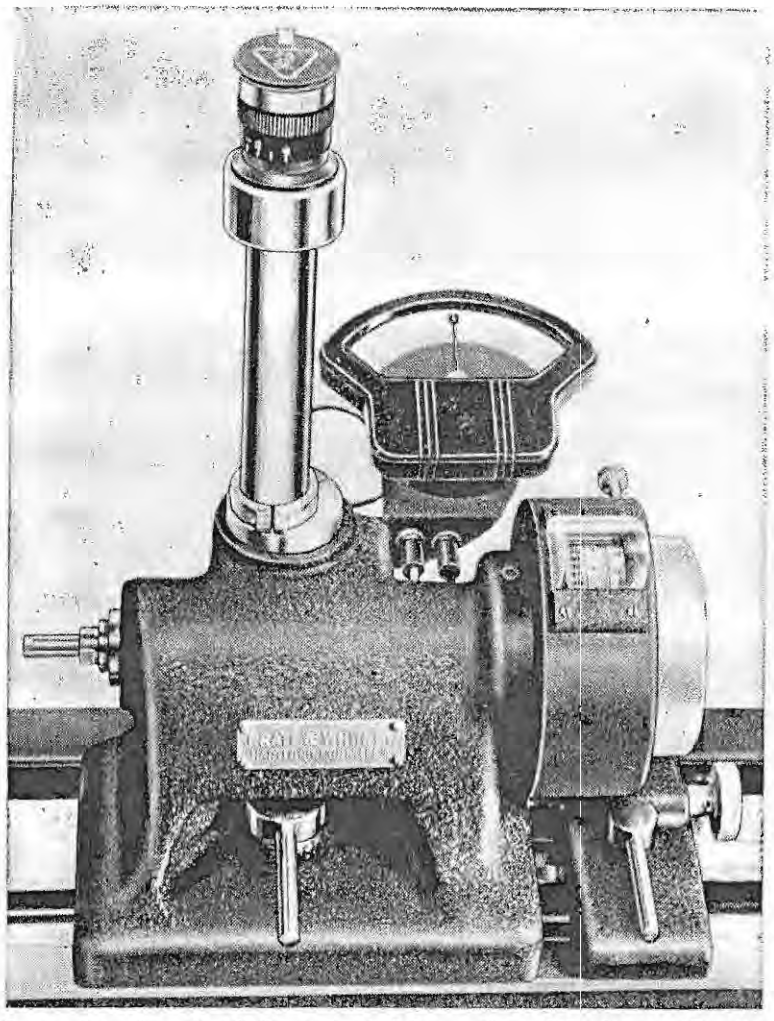


Fig. 6.21 Measuring head of Standard Measuring Machine. *Courtesy of Pratt & Whitney; Photo from Pratt & Whitney Division, Niles-Bement-Pond Co.*

The Electrolimit pressure tailstock controls measuring pressures from 1 to 2½ lb, in increments of 8 oz, through adjustments that are obtained with the pressure-adjusting knob. The pointer on the milliammeter, which is mounted on the measuring head, registers zero when the correct measuring pressure is applied.

The spindles on the measuring head and pressure tailstock are carbide-tipped for long wear.

The Standard Measuring Machine is calibrated at the standard measuring temperature of 68°F, and it should be used at that temperature for the most accurate measurements. Slight variations in room temperature, however, will affect the machine and work produced of iron and steel by nearly the same amount, and such variations may be ignored for work of ordinary accuracy.

A Standard Measuring Machine should be set up on a support that is strong and rigid enough to avoid vibrations and in a place where it will not be affected by direct sunlight or drafts through doors and windows. The manufacturer's instructions should be followed carefully in setting up and cleaning a new machine and for positioning the tailstock at zero on the bed. Thereafter, the position of the tailstock and of the microscope on the measuring head should not be changed because altering either of them will involve resetting the machine to zero.

To use a Standard Measuring Machine after it has been set to zero:

1. Open the cover over the master bar.
2. Loosen the binders on the measuring head and adjusting block and move the measuring head to the required plug on the master bar.
3. Clean the plug with a camel's-hair brush and cleaning fluid.
4. Bind the adjusting block to the bed.
5. Light the microscope lamp.
6. Position the measuring head accurately by moving it with the adjusting screw so that the line on the plug is midway between the lines in the microscope eyepiece.
7. Bind the measuring head to the bed.
8. Recoat the plug with an acid-free grease.
9. Cover the master bar.
10. Turn off the microscope lamp and cover the eyepiece. The measuring machine is ready for use. Keep the anvils and work clean if accurate results are to be obtained. Faces of the anvils may be cleaned with paper as described elsewhere in this chapter.

Measurements are read on the Measuring Machine's dials as shown in Fig. 6.22. Tenths and hundredths of an inch are read on the left-hand scale, thousandths and ten-thousandths on the center scale, and hundred-thousandths on the vernier.

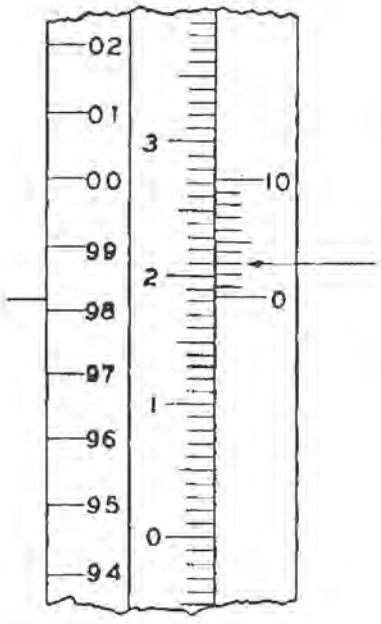


Fig. 6.22 Representation of dial reading on a Standard Measuring Machine. *Courtesy of Pratt & Whitney Division, Niles-Bement-Pond Co.*

The reading in this illustration is

Left-hand scale	0.98000 in.
Center scale	0.00180 in.
Right-hand scale	0.00003 in.
Total	0.98183 in. *Ans.*

This amount should be added to the setting on the master bar.

The Standard Measuring Machine is made in 12-, 24-, 36-, 40-, and 80-in. sizes. It is the most accurate commercial linear measuring tool made that is based on the micrometer and vernier principles. When greater measuring accuracy is required, some other principle must be employed.

QUESTIONS

1. Name the principal parts of an outside micrometer caliper.
2. Describe the design features of an English-measure micrometer caliper and tell how they enable the tool to be used for measurements to thousandths of an inch.
3. What is the purpose of the ratchet stop found on some outside micrometer calipers?
4. How would you clean the measuring surfaces of an outside micrometer caliper?
5. How should a micrometer caliper be cared for to ensure its accuracy over a long period of use?
6. Describe the design features of an English-measure vernier caliper and tell how they enable the tool to be used for measurements to thousandths of an inch.
7. Describe the design features of an outside micrometer caliper that is used for measurements to ten-thousandths of an inch.
8. Describe a Supermicrometer.
9. Describe a Standard Measuring Machine.

7

PRECISION GAGE BLOCKS EQUIPMENT FOR MEASURING WITH LIGHT WAVES

Precision Gage Blocks

After the parts or subassemblies are produced, many manufacturers assemble their product in an assembly plant that is convenient to their market or markets, which are often located at widely separated parts of the country. The ability to do this, particularly when the parts are produced to close tolerances for interchangeable and selective assembly, depends on each of the manufacturing plants having an accurate standard of length, that agrees with all the others, to control its production and inspection operations. "Industrial" standards of length that will supply the needed dimensional control are provided by precision gage blocks.

Precision gage blocks are pieces of alloy steel that are carefully heat-treated, ground, stabilized (seasoned artificially), and lapped so that their measuring faces on opposite sides or ends are flat and parallel and so that the distance between them is dimensionally accurate to within a few millionths of an inch of their basic sizes.

Grades of gage blocks

Gage blocks are made in four classes or grades of accuracy. Class AA, or laboratory gages, are accurate to within ± 0.000002 in. per block up to 1 in. in length, and to within ±0.000002 in. per inch of length above that. They are intended for use as master gages and should be used in an air-conditioned laboratory that is maintained at the international standard temperature of 68°F. Class AA gages are used to calibrate inspection and working gages and for similar applications that require the most precise dimensional control. Class A, or inspection gages, are accurate to within ±0.000004 in., and they are used in setting comparators and adjustable gages and to check the fixed gages used in manufacturing when working to tolerances which are specified in ten-thousandths of an inch.

Class B, or working gages, are accurate to within ±0.000008 in. and they are used for inspecting work, setting up machines, and laying out jobs when this degree of accuracy is needed in the shop and toolroom. Class C gages, accurate to ±0.000010 in., are classified as working gages also.

Sets of gage blocks

Precision gage blocks may be purchased individually or in sets that contain from 5 to 116 blocks to fit the needs of different applications and users. A popular set is one made up of 81 blocks in the four series of sizes listed in Table 3. These 81 blocks may be used individually or in combinations to make over 120,000 sizes in steps of one-thousandth of an inch from 0.100 to 0.200 in., and in steps of one ten-thousandth of an inch from 0.200 in. to over 12 in. Most of the sizes may be obtained by more than one combination so that the accuracy of one combination may be checked against another of the same size, and two or more combinations of the same size may be used in an inspection setup when it is necessary. The 5-block set, which will measure sizes from 0.0625 in. to 1.9375 in. by 0.0625 in. ($\frac{1}{16}$ in. to $1\frac{15}{16}$ in. by $\frac{1}{16}$ in.) is designed especially for checking the lead of micrometer screws.

Precision gage blocks are made in three principal types. The USA

type, produced by all gage-block manufacturers, is a rectangular block that measures about $\frac{3}{8}$ in. $\times$ $1\frac{3}{8}$ in. on two sides. This type is illustrated by Brown and Sharpe's Johansson or "Jo" blocks, shown in Fig. 7.1. Pratt and Whitney's Hoke blocks are about 1 in. square, and each block has a hole through its center for the insertion of tie rods when making combinations of blocks and attachments. Van Kuren blocks are solid 1-in. square gages. The Van Kuren Co.

Fig. 7.1 Johansson (USA Type) precision gage blocks—81-block set. *Courtesy of Brown & Sharpe Mfg. Co.*

also makes a $\frac{7}{8}$-in. diameter Microgage that has a total tolerance of 0.000020 in., and is designed expressly as a set of working gages.

Inspection of gage blocks

Precision gage blocks are subject to wear, and they should be inspected from time to time, preferably at periodic intervals. The National Bureau of Standards and manufacturers of gage blocks provide inspection service that includes the measurement and in-

spection of gage blocks, removal of high spots, a certificate of inspection which states the actual size and the variation from nominal size of each block, and a recommendation for the reconditioning or replacement of blocks when this is desirable. Note that a gage block need not measure its nominal size for use in precision work provided the deviation from its nominal size is known. The most accurate

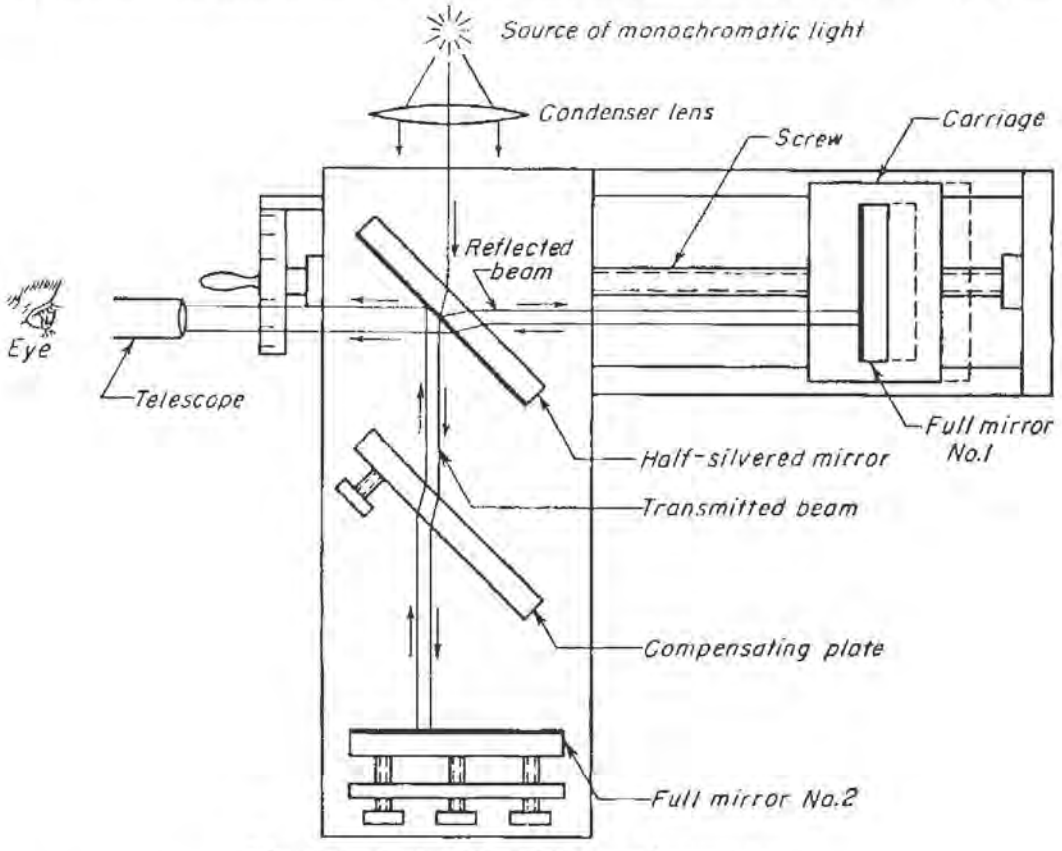


Fig. 7.2 Principle of the interferometer.

instrument known for measuring lengths of gage blocks and other standards of length is the interferometer.

The principle of the Michelson interferometer, which was used to determine the length of the meter in terms of light waves in 1894, is illustrated in Fig. 7.2. In this instrument, monochromatic light is divided by the half-silvered mirror into a reflected beam and a transmitted beam. Light of the reflected beam is turned back by full mirror 1 and passes through the half-silvered mirror a third time to reach the eye. Light of the transmitted beam is turned back by full mirror 2, passes through the compensating plate a second time, and is reflected from the back of the half-silvered mirror to

reach the eye. The compensating plate is employed to make the paths of the two rays in glass equal. When the divided beams come together at the eye, interference bands are formed if the instrument is in proper adjustment.

If the distance from the half-silvered mirror to full mirror 1 is about 0.0400 in. greater than the distance from the half-silvered mirror to full mirror 2, a large number of interference rings will be seen. When full mirror 1 is moved slowly toward the half-silvered mirror, the rings become wider and fewer in number. A ring will disappear each time the distance is decreased one-half of a wavelength of the light being used. In 1948, the National Bureau of Standards proposed that green light emitted by mercury 198, having a wavelength of nearly 21-millionths of an inch, be used as the international wavelength standard of linear measurement. The interferometer may be used to measure a gage block by substituting the block for full mirror 1 and counting the number of bands that disappear as the carriage is moved a distance equal to the length of the block. Or a block of unknown length may be compared with one of known length by moving the carriage a distance equal to the difference in their lengths.

Wear on precision gage blocks may be minimized in several ways: (*a*) chromium plating will give them an extra-hard wearing surface; (*b*) cemented carbide wear blocks, for use on the ends of combinations, where most impairment occurs in service, will protect regular steel blocks against wear to a certain extent; and (*c*) complete sets of solid carbide gage blocks are produced for use under severe service conditions. Chromium plating may be employed to restore worn gage blocks to their nominal sizes.

Combining gage blocks

Although gage blocks may be employed singly, most applications require a combination of several blocks to produce the sizes that are needed, and a systematic procedure should be followed in choosing those which are to be used. Assume that gage blocks to measure 3.1562 in. are to be assembled from an 81-block set:

1. Use the least possible number of blocks in making up the combination.
2. Refer to Table 3. Select a gage block, or a combination of blocks, that includes the last digit to the right in the required size. The 0.1002-in. block fulfills this condition. A combination of two blocks, 0.1004 in. + 0.1008 in. = 0.2012 in., for example, could be used, if necessary.
3. Perform the subtraction 3.1562 in. − 0.1002 in. = 3.056 in.
4. Select another block, or combination of blocks, that includes the last digit in this remainder.
5. Proceed to select all of the blocks necessary to make up the required size in this manner. The whole procedure is indicated by the series of selections, subtractions, and proof, as shown below.

Blocks selected	*Subtractions*
	3.1562 in.
0.1002 in.	−0.1002 in.
	3.056 in.
0.106 in.	−0.106 in.
	2.950 in.
0.150 in.	−0.150 in.
	2.800 in.
0.800 in.	−0.800 in.
	2.000 in.
2.000 in.	−2.000 in.
3.1562 in. (Proof)	0.000 in.

Two or more gage blocks are combined for handling and use by a process called "wringing." The blocks are cleaned carefully, the contacting surfaces are wiped on the wrist or palm of the hand, and they are wrung as shown by the four illustrations in Figs. 7.3 to 7.6, inclusive. Put the contacting surfaces together, as shown in Fig. 7.3; oscillate the blocks to be sure that there is no foreign matter between them, as shown in Fig. 7.4; slide the blocks halfway off each other, as in Fig. 7.5; and finally, slide the blocks together with

slight pressure to produce the assembly shown in Fig. 7.6. If the blocks are clean, and if their surfaces are in good condition, they will adhere to each other as shown in the last illustration. This adhesion of gage blocks is variously attributed to three causes re-

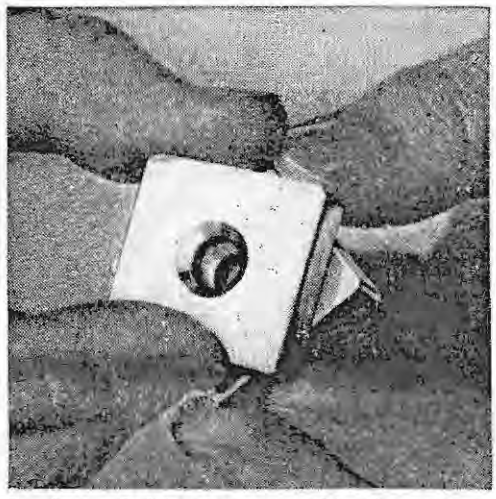


Fig. 7.3 Wringing gage blocks, step 1. *Courtesy of Pratt & Whitney; Photo from Pratt & Whitney Division, Niles-Bement-Pond Co.*

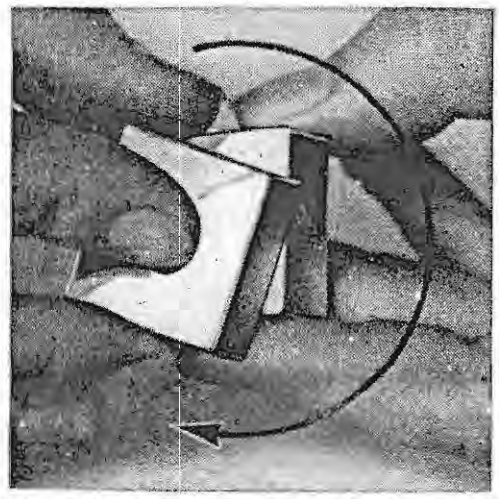


Fig. 7.4 Wringing gage blocks, step 2. *Courtesy of Pratt & Whitney; Photo from Pratt & Whitney Division, Niles-Bement-Pond Co.*

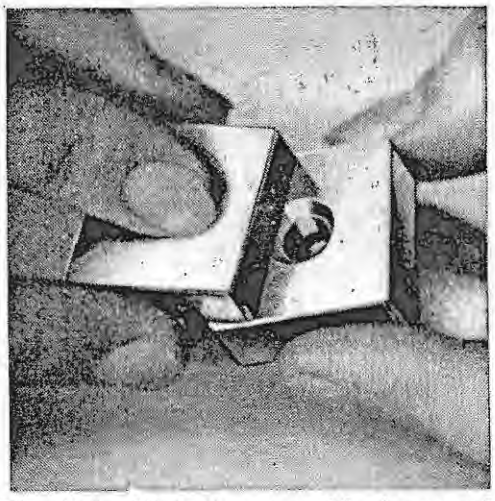


Fig. 7.5 Wringing gage blocks, step 3. *Courtesy of Pratt & Whitney; Photo from Pratt & Whitney Division, Niles-Bement-Pond Co.*

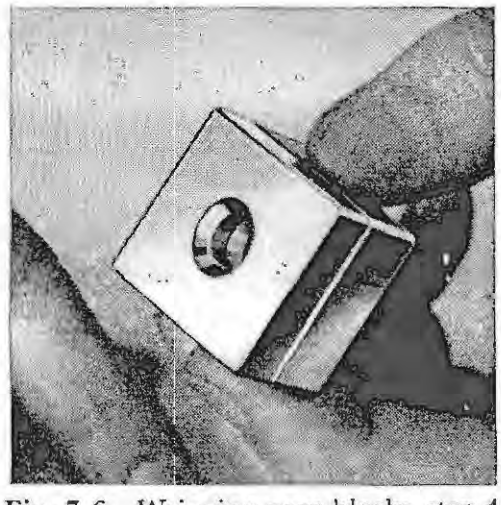


Fig. 7.6 Wringing gage blocks, step 4. *Courtesy of Pratt & Whitney; Photo from Pratt & Whitney Division, Niles-Bement-Pond Co.*

lated to their almost perfectly flat surfaces: (*a*) atmospheric pressure holds the blocks together because no air remains between them after wringing; (*b*) a thin film of oil remains on the surfaces after they are cleaned and wiped, and surface tension of the oil on steel

holds them together; and (*c*) the metal surfaces are in such intimate contact that molecular attraction holds them together.

Care of gage blocks

Gage blocks must be cared for properly if they are to give satisfactory service.

1. Keep the gage blocks in their case when they are not in use. Clean the case regularly.
2. Clean gage blocks with a clean chamois and solvent to remove their coating of rust preventive before using them (see (3)).
3. Clean gage blocks after they are used, coat them with a rust preventive, and store them in their case. Do not handle the blocks by their measuring surfaces after cleaning them in preparation for storage.
4. Do not bump or scratch the measuring faces of gage blocks. If accidents do occur, remove the swellings around bumps and the wire edges along scratches with a hard Arkansas oilstone.
5. Do not leave gage blocks wrung together for more than a few hours. If allowed to stand too long, they may adhere so closely that they will be damaged in separating them.
6. Separate blocks by sliding them off each other; that is, by reversing the process used to wring them together.

Gage-block accessories

Applications of gage blocks may be simplified and extended by employing accessories that are designed for use with them. The set of accessories illustrated in Fig. 7.7 consists of four adjustable holders, three pair of caliper jaws, one center point, one scriber, one triangular straightedge, and one foot block. Other accessories that are available, but which are not shown in this set, consist of trammel points and a sine bar. A pair of caliper jaws and a combination of gage blocks assembled in a holder will make an outside or inside caliper gage, as required. Two sets of caliper jaws and two com-

binations of gage blocks in a holder will make up a "go–not go" gage. The center point and scriber, or a pair of trammel points assembled in a holder with gage blocks, will make a divider or trammel. Scriber, gage blocks, and foot block assembled with an adjustable holder make a height gage.

Fig. 7.7 Gage-block accessories. *Courtesy of Brown & Sharpe Mfg. Co.*

Gage blocks and their accessories provide a means of comparing work directly with "industrial" standards of length that are accurate to within a few millionths of an inch of a given size. Their use in this manner, however, does not give information about the amount that the work varies from the standard which is used. When knowledge of this kind is required, either equipment for measuring with light waves or a high-accuracy comparator of some kind must be used.

Light waves have all of the properties that are required in a standard of length for measuring to millionths of an inch: the

lengths of light waves have been determined accurately to millionths, the waves are constant in length, they are not subject to wear, and they are easy to use.

Industrial Equipment for Measuring with Light Waves

The equipment that is used for industrial measurements with light waves consists of a monochromatic lamp, two optical flats, and precision gage blocks or other gages of certified lengths. A steel

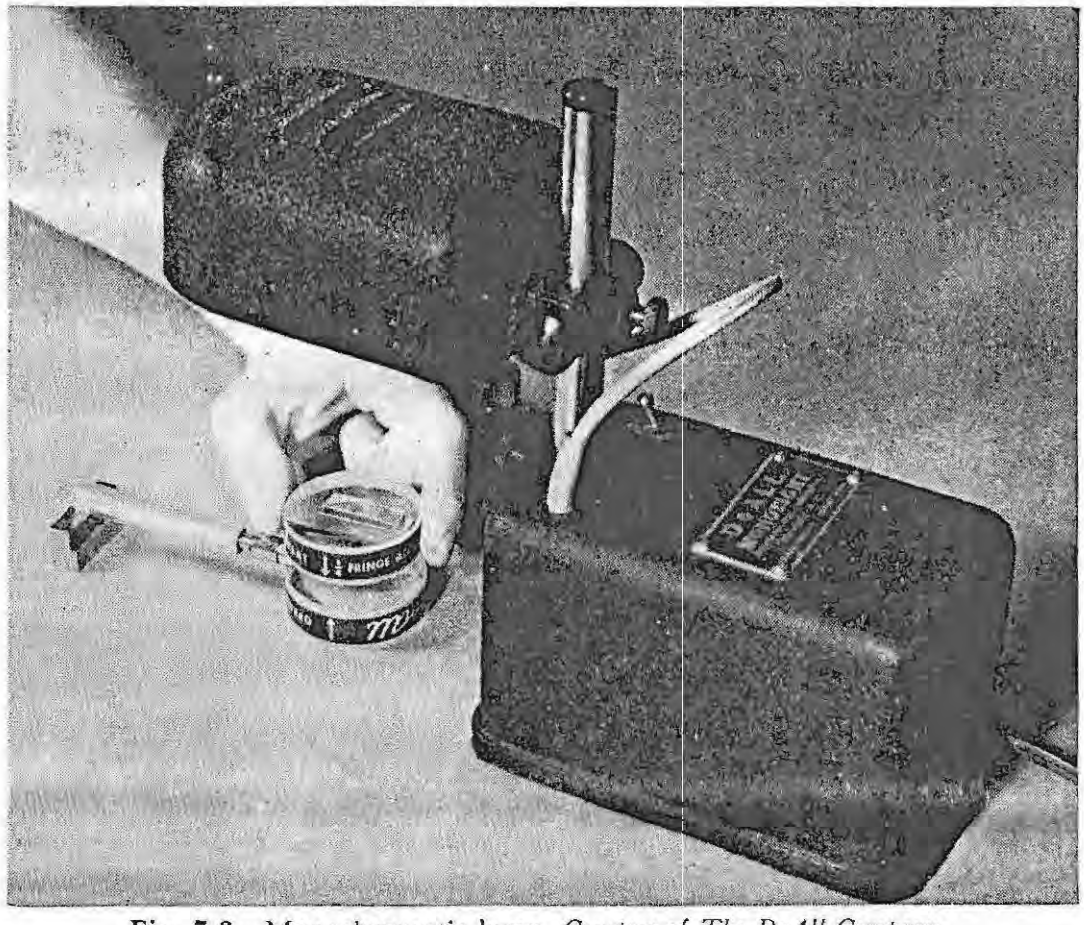


Fig. 7.8 Monochromatic lamp. *Courtesy of The DoAll Company.*

flat may be substituted for one of the optical flats to reduce expense. This equipment is shown set up for use in Fig. 7.8.

A *monochromatic lamp* is a lamp that emits light of a single wave length or color. The customary source of light for industrial measurements is a tube filled with helium that gives off a nearly monochromatic yellow light which has a wavelength of 23.2 millionths (0.0000232) of an inch.

Optical flats are glass or fused-quartz disks that are ground and polished on both sides. Fused quartz is preferred to other materials because it has better wearing qualities and because heat affects it less. The flats are made in several grades of accuracy that vary 0.000010 to 0.000001 in. from absolute flatness. Only one side needs to be flat.

A steel or toolmakers' flat is made of alloy steel; heat-treated, stabilized, ground, and lapped to an optically flat surface on one or both sides.

Three types of tests or measurements may be made with equipment for measuring with light waves:

1. *Dimensional:* The size of a workpiece is compared with a standard of known length, usually a precision gage block.
2. *Taper or parallelism:* The workpiece is compared with an inspection gage that has parallel measuring faces and is of known size.
3. *Flatness:* The workpiece is tested directly with an optical flat.

Equipment for measuring the size of work with light waves is shown in diagrammatic form in Fig. 7.9. To make a setup like this:

1. Clean the parts with a soft tissue.
2. Wring the inspection gage to the steel flat.
3. Assemble the other parts in the relationship shown in the illustration.
4. Move the assembly under the monochromatic lamp and light the lamp.
5. Press the optical flat down to a seat on the inspection gage and the work to be measured.
6. View the top of the inspection gage from as nearly overhead as possible.

If the work being measured is not the same size as the inspection gage (in Fig. 7.9, the work being measured is represented as being larger than the inspection gage), one side of the optical flat will bear on one edge of the inspection gage and the other side will be raised above it to form an air wedge between the lower surface of the optical flat and the upper surface of the inspection gage. This causes a series of alternate dark and bright bands to appear on the

upper surface of the inspection gage. In Fig. 7.9, dark bands are represented by the lines numbered 0, 1, 2, 3, and 4. The explanation for the appearance of these bands is made in paragraphs to follow, with reference to Figs. 7.10 to 7.13, inclusive.

In Fig. 7.10, which represents an enlarged view of the air wedge, some light from the monochromatic lamp is depicted as being re-

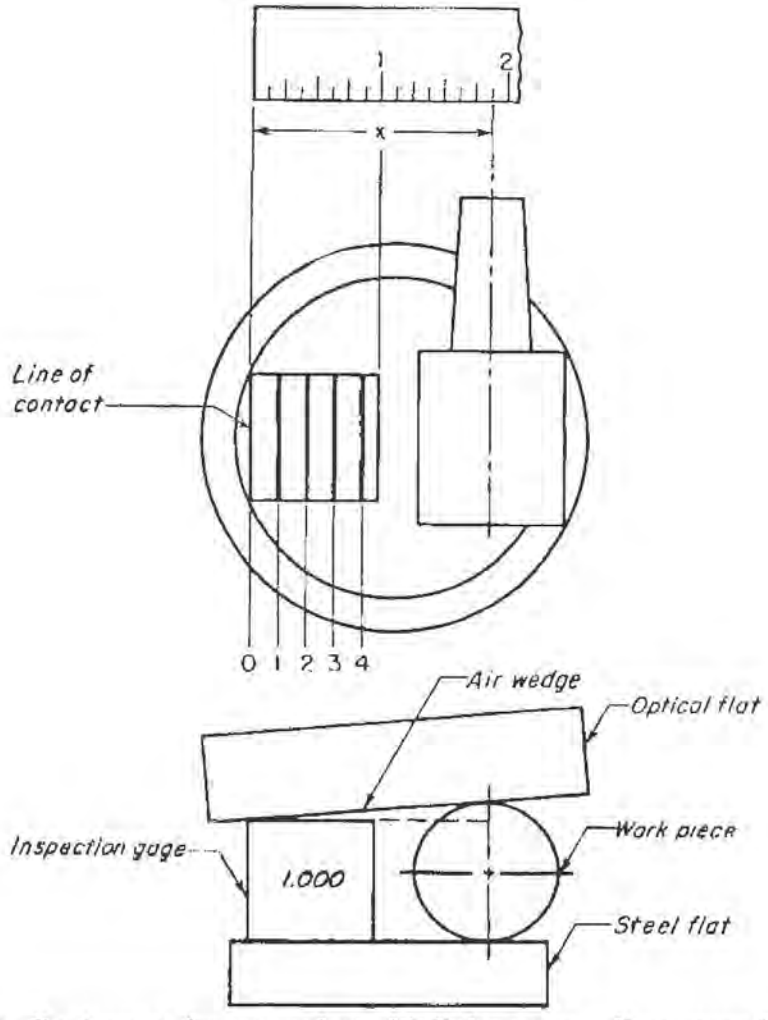


Fig. 7.9 Equipment for measuring with light waves—diagrammatic views.

flected to the eye from D_f on the lower surface of the optical flat while the remainder of the light continues across the air wedge to be reflected from the upper surface of the inspection gage. If the light waves from these two points are in phase when they reach the eye, one will reinforce the other, as represented at *a* in Fig. 7.11, and a bright band of color will appear. But if the waves are 180 deg or ½ of a wavelength out of phase, one will interfere with the other, as

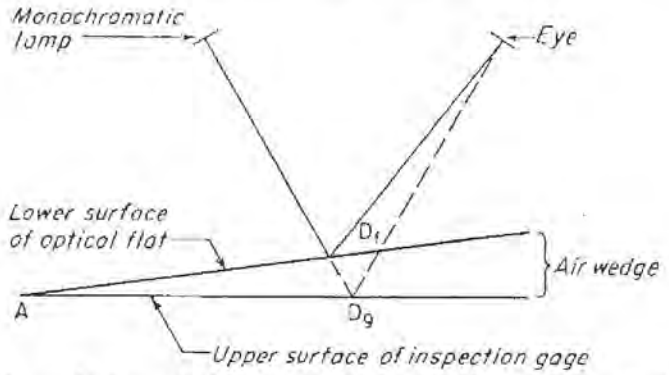


Fig. 7.10 Enlarged view of air wedge. Representation of paths of light waves.

represented at *b* in the same figure, and a dark interference band will appear. The conditions that cause the appearance of light and dark bands are explained more fully in succeeding paragraphs.

A 180 deg or ½-wavelength instantaneous change of phase takes place whenever a light wave passes from a rarer medium to a denser medium. This is the condition shown at *A* in Figs. 7.10 and 7.12 which represents the point of or line of contact between the lower surface of an optical flat and the upper surface of an inspection gage. A dark spot or band will appear at *A*, therefore, because waves reaching the eye from the two surfaces meeting at that point or line will be ½ of a wavelength out of phase. This effect serves as one means of identifying the point or line of contact between the two surfaces.

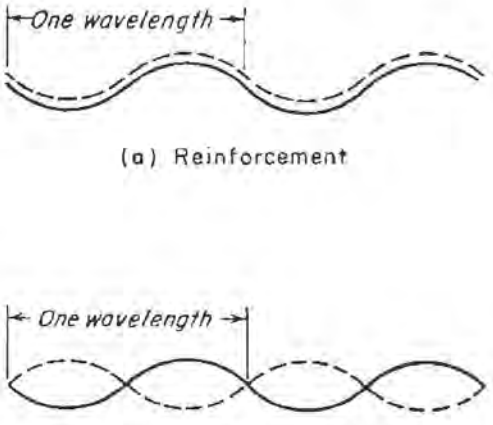


Fig. 7.11 Representation of reinforcement and destructive interference of light waves.

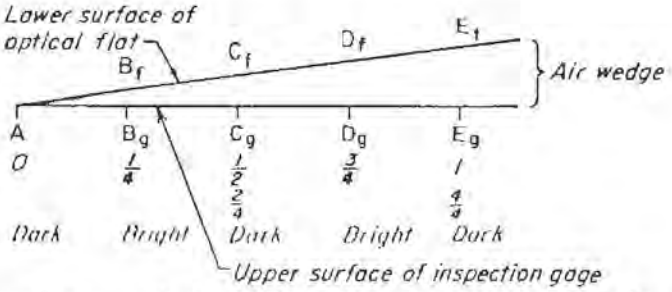


Fig. 7.12 Enlarged view of air wedge. Representation of dark- and bright-band relationships.

The same condition occurs when light passes from air in the air wedge to the surface of the inspection gage. Consequently, light waves change phase at all points over the inspection gage.

In Fig. 7.12, the distance B_fB_g represents ¼ of a wavelength. Light that is reflected from B_g must cross the air wedge twice to reach the eye; therefore

½-wavelength difference in distance traveled
+ ½-wavelength change in phase at B_g
1-wavelength total change *Ans.*

Light from B_f and B_g will be in phase at the eye, the waves will reinforce each other, and a bright band will appear.

The distance C_fC_g, Fig. 7.12, represents ½ or ¾ of a wavelength. Light that is reflected from C_g must travel 1 wavelength farther than that from C_f to reach the eye; consequently

1-wavelength difference in distance traveled
+ ½-wavelength change in phase at C_g
1½-wavelength total change *Ans.*

Light from C_f and C_g will be ½-wavelength out of phase at the eye, there will be destructive interference, and a dark band will appear.

A dark band will appear whenever the height of the air wedge equals an even number of ¼ wavelengths as at C_fC_g and E_fE_g, and a bright band will appear whenever it equals an odd number of ¼ wavelengths as at B_fB_g and D_fD_g. Dark bands are used in measuring with light waves because a dark band appears at 0 on the scale. Each consecutive dark band on the scale represents a difference of ½ of a wavelength in the height of the air wedge, and this distance is

$$\tfrac{1}{2} \times 0.0000232 \text{ in.} = 0.0000116 \text{ in.}$$

In Fig. 7.9, the line of contact between the optical flat and the inspection gage is at 0, the width of the inspection gage is 1 in., the width of the air wedge is 1⅞ in., and 4½ dark bands appear on the inspection gage. It is evident that the number of dark bands (x) in

the width 1⅞ in. must be calculated. In this case, it is simplest to reduce the mixed numbers to improper fractions and to establish a proportion for determining the number of bands.

$$1\tfrac{7}{8} = \tfrac{15}{8}$$
$$4\tfrac{1}{2} = \tfrac{9}{2}$$
$$1 : \tfrac{15}{8} :: \tfrac{9}{2} : x$$
$$x = \tfrac{15}{8} \times \tfrac{9}{2} = \tfrac{135}{16} = 8.4\text{-bands high} \qquad \textit{Ans.}$$

Since each dark band indicates a difference of 0.0000116 in. in the height of the air wedge, the diameter of the plug gage is

$$0.0000116 \text{ in.} \times 8.4 = 0.0000974 \text{ in.}$$

larger than the inspection gage. It is indicated that the inspection gage measures 1.000 in.; therefore, the diameter of the plug gage is 1.000 in. + 0.0000974 in. = 1.0000974 in.

Conversion of interference bands to millionths of an inch may be simplified by the use of Table 4.

In Fig. 7.9, the interference bands are represented as being parallel to the sides of the inspection gage and to the axis of the work piece. This signifies that the work piece is cylindrical; that is, it is not tapered. In Fig. 7.13, however, the interference bands are represented as crossing the inspection gage at an angle. This signifies that the work is tapered; that is, there is a gradual and uniform change in its diameter from one end to the other.

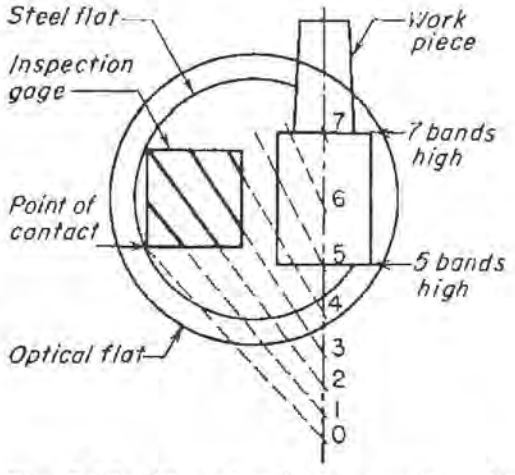


Fig. 7.13 Test showing tapered condition of work.

A taper is described by stating its difference in diameters at two points a given distance apart. To determine that difference with light-wave equipment, the two diameters are compared with the size of an inspection gage by projecting the interference bands to the center line of the work piece, as shown in Fig. 7.13, and estimat-

ing the number at each end. In this figure, the large end of the work piece is seven bands higher than the inspection gage, and the small end is five bands higher. The difference in diameters, or taper, is two bands. From Table 4, this equals 0.0000231 in.

The test for flatness is illustrated in Fig. 7.14. In making this test, the optical flat is pressed firmly or wrung on the surface to be inspected; then the setup is observed under the monochromatic lamp. A bright spot surrounded by concentric interference bands indicates a low spot on the work piece, but a dark spot surrounded by concentric bands may indicate either a high or low spot. To determine which condition exists, press down on the edge of the optical flat. If the spot is high, it will move toward the place where pressure is applied, and the number of bands will decrease on the pressured side and increase on the opposite side. Pressure and observation of the number and movement of interference bands, therefore, is another means of locating the point or line of contact between an optical flat and a workpiece or gage block. Figure 7.15, represents the appearance of several common interference-

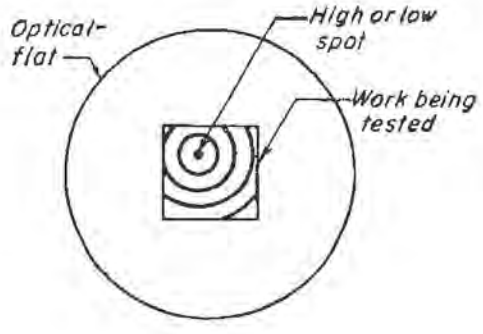


Fig. 7.14 Test for flatness.

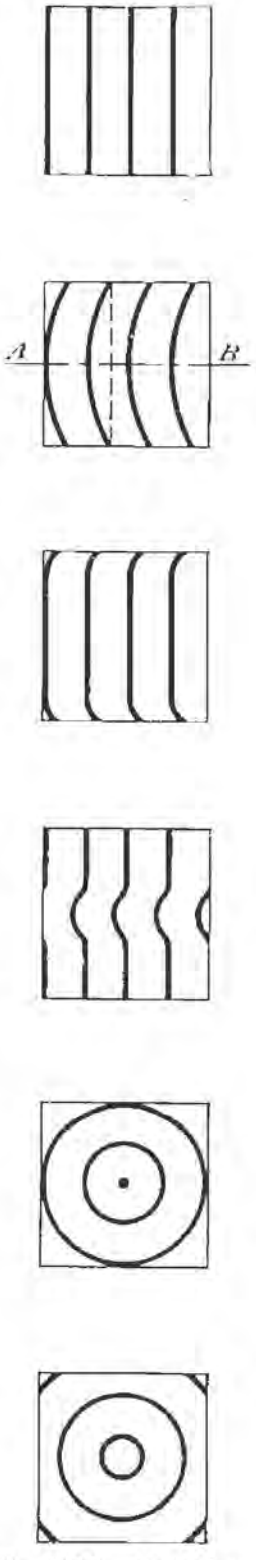


Fig. 7.15 Interference-band patterns.

band patterns. A pattern may occur alone, as shown in these drawings, or in various combinations.

Para-Plane Gage

The Para-Plane gage, shown in Fig. 7.16, is an instrument for determining the flatness and parallelism of reflecting surfaces. Surface flatness is tested by observing interference bands in the light

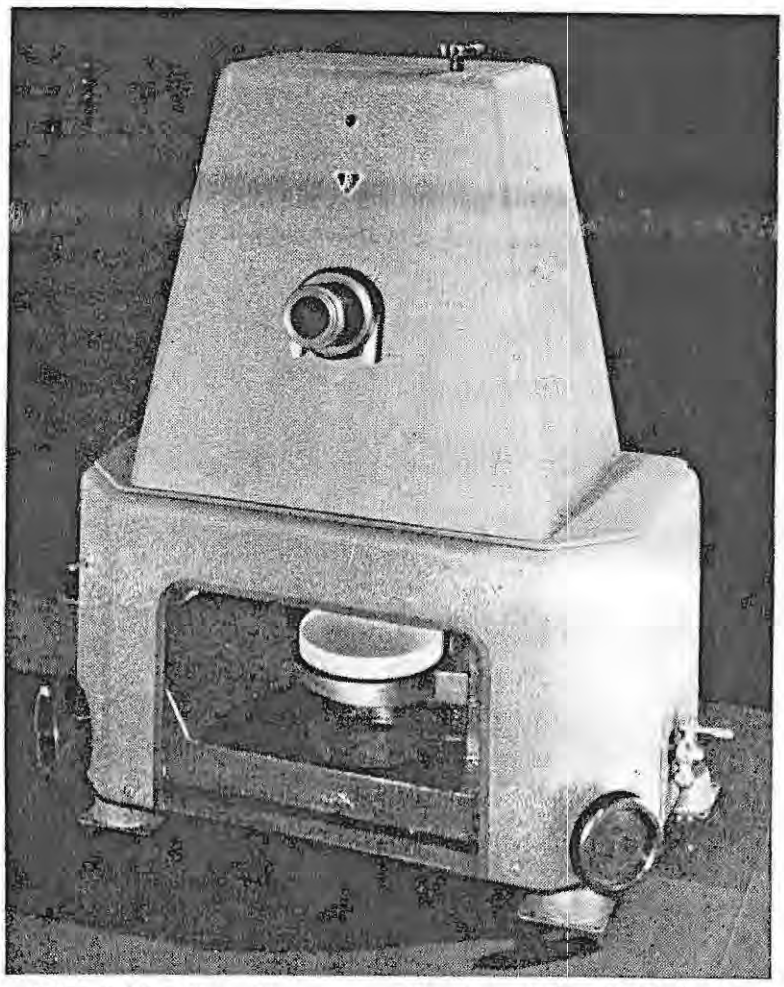


Fig. 7.16 Para-Plane gage. *Courtesy of Bausch & Lomb.*

being reflected between a master flat, which has a surface accuracy of 0.000001 in., and the work being tested. The operator observes fringes or bands essentially like those seen with an optical flat, and from them he is able to determine the degree of flatness of the surface under observation.

Optical Parallels

Optical parallels are double-surface optical flats whose surfaces are both flat and parallel. They may be obtained singly or in sets of different thicknesses for checking the flatness and parallelism of the measuring faces on outside micrometer caliper spindles and anvils, as shown in Fig. 7.17. Worn measuring faces may be restored to accuracy by lapping them.

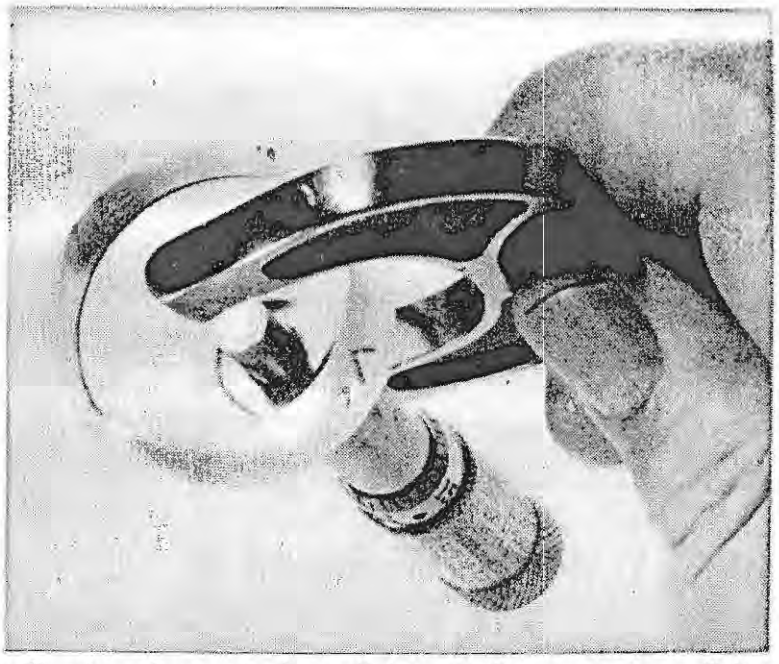


Fig. 7.17 Application of an optical parallel to test flatness and parallelism of micrometer spindle and anvil. *Courtesy of The Van Keuren Co.*

Light-wave Micrometer

Micrometer and vernier principles of measurement and a light-wave pressure indicator are combined in the 0- to 3-in. light-wave micrometer that is illustrated in Fig. 7.18. This bench-type micrometer consists of an elongated base and frame, a precision micrometer head, a cemented carbide anvil, and the light-wave pressure indicator.

Special features of the micrometer head consist of a cemented carbide-tipped micrometer screw, an 8-in. diameter wheel mounted on the thimble, and an adjustable glass index with a hairline engraved on it. The ½-in. diameter micrometer screw has 40 threads per inch, and the wheel has 250 divisions; therefore, this micrometer

will measure to ten-thousandths of an inch directly. The index line, on the adjustable glass index, corresponds to the longitudinal reference line on the barrel of a regular outside micrometer caliper. A vernier on the index arm has 10 divisions that occupy the same space as 9 divisions on a scale beneath it, and this permits measurements to hundred-thousandths of an inch.

The light-wave pressure indicator consists of a rectangular, chromium-plated steel flat, a rectangular optical-glass flat, and a red selenium glass screen which are arranged on the base of the microm-

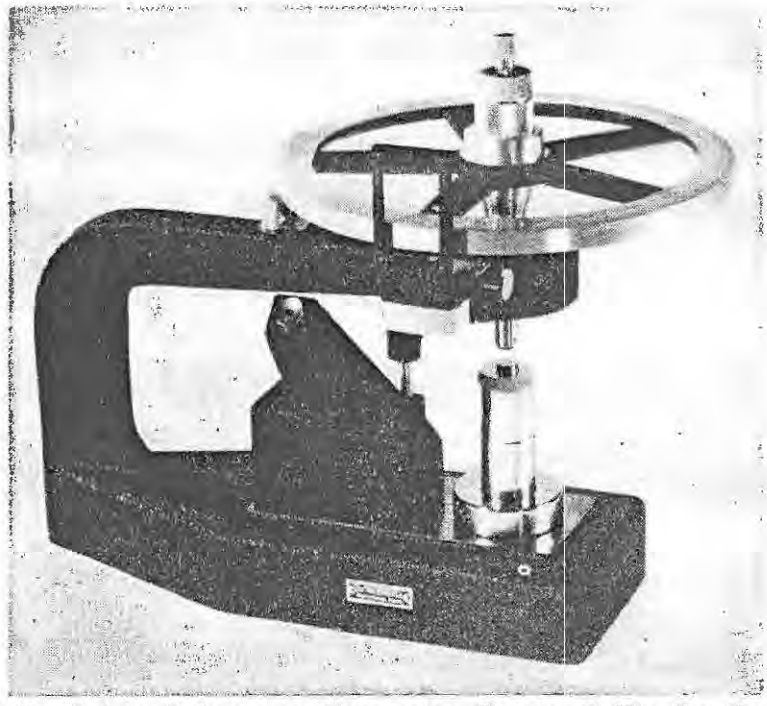


Fig. 7.18 0–3 in. light-wave micrometer. *Courtesy of The Van Keuren Co.*

eter in such a way that when pressure of the spindle on the anvil or work springs the frame slightly upward, light-wave interference bands are caused to move past a reference line on the steel flat. When the micrometer is in proper adjustment, and there is no pressure on the spindle, two or three interference bands show between the reference line and the left-hand edge of the steel flat. When the micrometer is in use, each interference band that moves up to the reference line indicates that a measuring pressure of 6 oz has been applied to the spindle. The micrometer may be used at measuring pressures of 0 to 2½ lb; therefore, it may be employed to measure

rubber and plastics at the recommended pressures of 1 or 2 oz and to measure screw threads by the three-wire method at the recommended pressures of 1 and 2½ lb. Repetitive measurements that are accurate to ten-thousandths of an inch may also be made with this instrument. The glass index is adjustable so that its reference line may be set to 0 on the micrometer wheel at the various measuring pressures which are used. The light-wave pressure indicator is enclosed in a housing to prevent dust or oil spray from entering into the air wedge and disturbing the adjustment between the steel flat and the optical flat.

The light-wave micrometer that is illustrated has a measuring range of 0 to 3 in. through the use of either 1- or 2-in. long by 1-in. diameter spacer blocks which may be inserted, when required, between the cemented carbide anvil and the subanvil on the base of the instrument. Other models of the light-wave micrometer have measuring ranges of 0 to 1 in. and 0 to 2 in. The latter models do not have the vernier for reading to hundred-thousandths of an inch, and the light-wave pressure indicator is not enclosed in a housing.

To use the light-wave micrometer: (*a*) set the tool on a workbench or table so that the micrometer head is at the right and so that the light will fall on the red selenium glass screen from above and back of the instrument; (*b*) clean the measuring faces of the anvil and spindle; (*c*) observe the steel flat and turn the spindle until slight movement of the interference bands shows that the spindle is in contact with the anvil; (*d*) continue to turn the spindle until the number of bands that indicate the desired measuring pressure have moved up to the reference line on the steel flat; (*e*) set the index line to 0 on the measuring wheel. The tool is ready to use.

QUESTIONS

1. What are precision gage blocks?
2. Describe the four classes or grades of dimensional accuracy in which precision gage blocks are produced.
3. Describe the process of wringing gage blocks together.
4. What care should be observed to keep gage blocks in good condition?

5. Name the items of equipment that are needed for industrial measurements with light waves.

6. What is monochromatic light?

7. What is the wavelength of the monochromatic light commonly used for industrial measurements with light waves?

8. How are interference bands formed when light-wave equipment is used in making measurements?

9. What is the dimensional significance of each dark band that is seen?

8

PLAIN GAGES

Interchangeable manufacturing is based, in part, on measuring the components of products to determine if their dimensions are within the limits specified for them. It would be slow and expensive to do this with the measuring tools that were described in earlier chapters of this text; therefore, gages of various kinds are used to measure work during its production and inspection.

The word *gage* will be used here to mean a device for determining if one or more dimensions of a manufactured part are within specified limits. The advantages of a gage over other measuring tools lie in its speed of operation, its accuracy, and its freedom from error even when it is used by a comparatively unskilled workman or inspector.

Many kinds of gages are made. Some are fixed as to size, and others are adjustable. Some indicate variations in the sizes that are measured, others do not. Some are operated manually, others operate automatically. Some are specially designed to measure a particular piece of work, and others are made to standard designs.

Standard and general designs for gages in common use are covered by American Gage Design Standards,[1] abbreviated AGD, adopted by gage manufacturers and users to simplify gaging prac-

[1] "Gage Blanks," Commercial Standard C58-51, United States Government Printing Office, Washington, D.C., 1951.

tice and to secure interchangeability of components through the process of standardization.

Classification of Gages

Gages may be classified in a number of ways:

1. According to accuracy or use as master, inspection, and working gages.
2. According to use for checking tolerance or limits as limit or "go–not go" gages.
3. According to design for measuring internal or external dimensions as plug, ring, snap, length, etc., gages.
4. According to use for measuring specific shapes or forms as plain cylindrical, thread, taper, spline, etc., gages.
5. As indicating gages or comparators that show variations in size or contour.
6. In various combinations of the foregoing as, for example, thread limit snap gages, etc.

Master gages

A master or reference gage is one that is used to check and set micrometers, adjustable snap gages, comparators, and other tools which are used as inspection or working gages. A master gage is always an internal or plug gage; that is, one which is designed to measure an inside dimension. It should represent, as nearly as possible, the basic size of the part that is to be measured. When the associated inspection or working gage is an internal gage also, the master gage is its duplicate in form, and one is checked against the other by comparison measurements. When the inspection or working gage is an external gage, however, it may be referrred directly to the master gage. An external gage is one that is used to measure an outside diameter.

Limit gage

A limit gage is used to check one of the limiting sizes of a workpiece that is dimensioned with tolerance. Since two limits must be

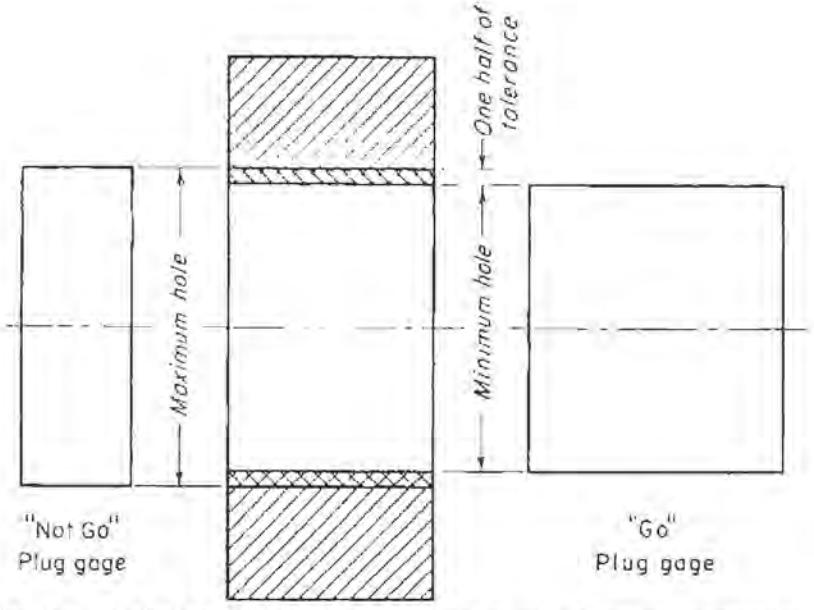


Fig. 8.1 Relationships between "go not go" plug gages and hole.

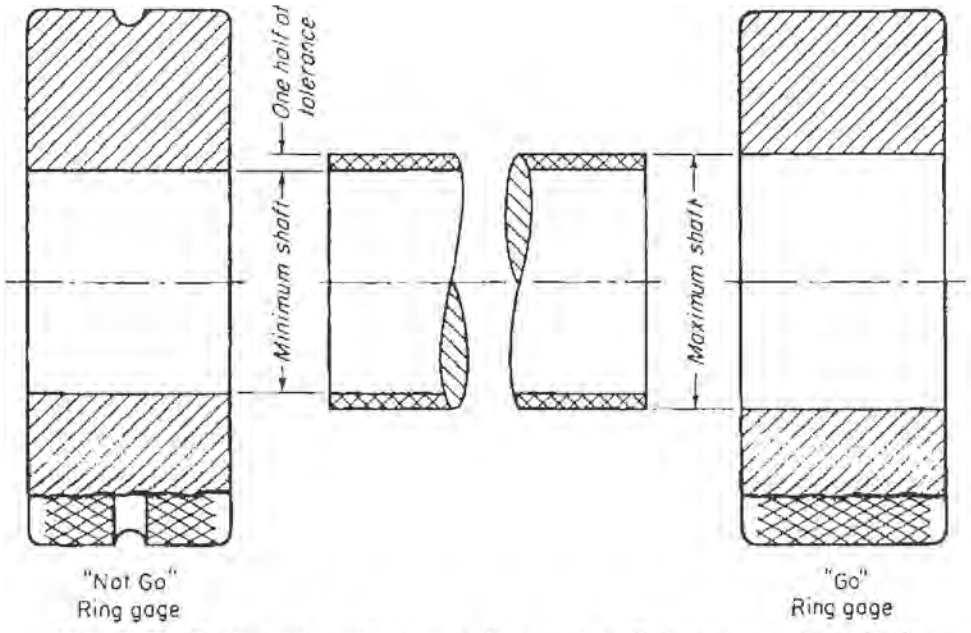


Fig. 8.2 Relationships between "go-not go" ring gages and shaft.

checked for any basic size that is inspected, two limit gages, called "go" and "not go" gages are required to measure them. A "go" plug gage should enter a hole being inspected, and a "not go" gage should not enter it. A "go" plug gage, therefore, controls the minimum size of a hole, and a "not go" plug gage controls its maximum size. Similarly, a "go" ring gage should go on a shaft being measured, and a "not go" gage should not go on it. A "go" ring gage, therefore, controls the maximum size of a shaft, and a "not go" ring gage controls its minimum size. These relationships between limit gages and work are illustrated in Figs. 8.1 and 8.2.

Gagemakers' Tolerance

A gage, like any other manufactured product, cannot be made to an absolute size, and tolerance must be permitted in its production. In general, gage tolerance should be as large as possible because the specification of a small tolerance will delay its production, make it cost more, and shorten its useful service life. There is no recognized rule to govern the amount of tolerance that should be permitted in the production of any gage. One common practice, for example, uses 10 per cent of the work tolerance for both inspection and working-gage tolerance. Another practice uses 5 per cent of the part tolerance as inspection-gage tolerance and 10 per cent as working-gage tolerance. Other variations in practice may be employed also.

Plain cylindrical plug and ring gages are made in five standard classes of tolerance to meet the needs of industry. These gagemakers' tolerances, which are listed in Table 5, find application as follows:

1. Class XX gages are precision lapped to the highest accuracy practicable. Plain cylindrical plug gages only are produced in this class, and they are used principally for master or reference gages.
2. Class X gages are precision lapped to close tolerances, and they are used to inspect work requiring the highest accuracy.
3. Class Y gages are lapped to larger tolerances than Class X, and they are used for inspection and working gages. Unless otherwise specified, plug gages are customarily made to this class of tolerance.

4. Class Z gages are precision ground and polished; they are suitable for use on most commercial production. Unless otherwise specified, ring gages are customarily made to this class.

5. Class ZZ gages have a ground finish, and this class is used for ring gages only when work tolerances are liberal.

To illustrate the calculation of gagemakers' tolerance by applying the 10 per cent rule previously mentioned, assume that a plug gage is required to check a 1¼-in. hole to a tolerance of +0.0006 in. − 0.0000 in. The gagemakers' tolerance will be

$$0.0006 \text{ in.} \times 0.10 = 0.00006 \text{ in.}$$

Examination of Table 5 shows that a Class X 1¼ in. gage has the required gagemakers' tolerance.

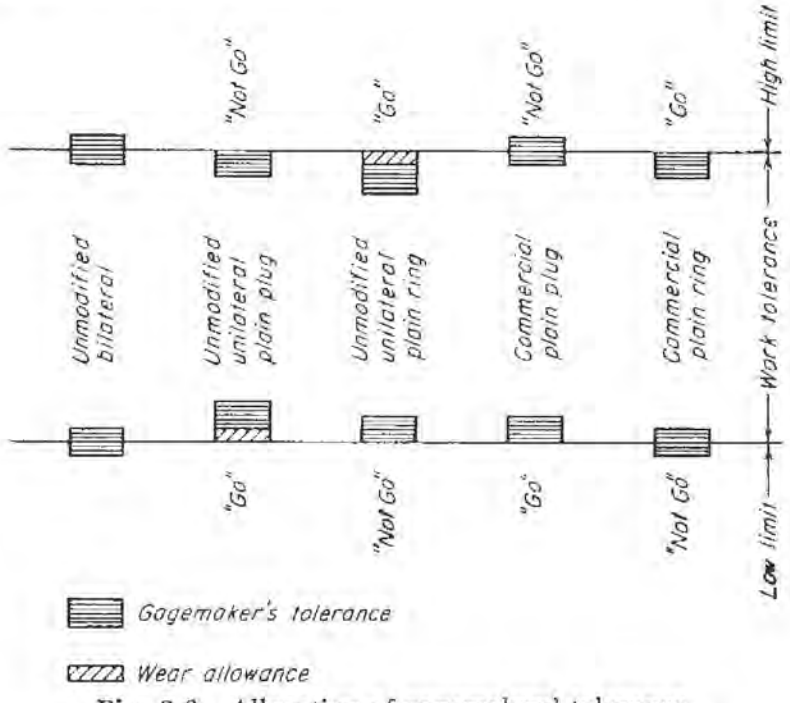


Fig. 8.3 Allocation of gagemakers' tolerance.

There are two basic systems of allocating gagemakers' tolerance, and both may be modified in various ways. Examination of Fig. 8.3. shows that one half of the gage tolerance is allocated plus and one half minus with respect to the work tolerance in the unmodified bilateral system, and that all of the gage tolerance is allocated within the work tolerance in the unmodified unilateral system. One commercial practice allocates gage tolerance plus on the "go" plug gage and one-half plus and one-half minus on the "not go" gage. And it allocates gage tolerance minus on the "go" ring gage and

one-half plus and one-half minus on the "not go" gage. Each basic system, including its modifications, has advantages and disadvantages depending on the point of view. In the unmodified bilateral system, for example, a new "go" plug gage will pass some oversize holes, but it will have a relatively long service life. In the unmodified unilateral system, on the other hand, a new "go" plug gage will not pass any oversize holes, but it will have a relatively short service life. Since there are two basic systems of allocating gagemakers' tolerance, and various ways of modifying both of them, a gage designer must follow the policy of his company when specifying dimensions.

Wear Allowance

Gages, and "go" working gages especially, wear every time they are used. This must be given consideration when designing gages because wear reduces the size of a "go" plug gage, for example, so that it will pass undersized holes after a period of use. Similarly, wear increases the size of a "go" ring gage so that it will pass oversized shafts after a time.

The effect of wear on gages may be counteracted in various ways. One method consists of adding a wear allowance to the nominal diameter of a plug gage, and subtracting it from a ring gage, before allocating the gagemakers' tolerance. The amount to be provided for wear, in any case, depends on a number of factors such as use as an inspection or working gage, use as a "go–not go" gage, and the material of which the gage is made. A working gage that is used in the grit and oil at a production machine will wear faster than one which is used in the cleaner surroundings of an inspection department. And a "go" gage that usually slides in contact with the surface of work being measured will wear more rapidly than a "not go" gage. In fact, wear allowance is seldom specified for "not go" gages. Chromium plating gives new gages a hard, wear-resisting surface, and it may also be used to renew the size of worn gages. Plating, and some other surface treatments, give warning as to when a gage wears because the different color of the base metal becomes exposed. Nitriding is a heat-treating process that increases gage life by producing a very hard skin on the surface of the tool. Hard facing with

Stellite and similar alloys also provides a wear-resistant surface. Cemented carbide, Norbide,[1] synthetic-sapphire wear strips, or solid gages made of these materials may be used when service conditions are severe. So many factors enter into the problem of gage wear that no generally accepted rule can be stated for determining wear allowance. Since a number of factors affect wear on gages, a gage designer must be guided by the policy of his company when specifying wear allowance.

Plain Cylindrical Plug Gages

A plug gage is one that has outside measuring surfaces which are arranged to measure the size of a hole. It may be cylindrical or conical, of any cross-sectional shape, and plain or threaded.

A *plain cylindrical plug gage* is a cylinder, accurately finished to size, which is used to measure the diameter of a cylindrical hole. It may consist of one or two gaging members, as required, attached to a handle. Four separate AGD standard designs have been adopted for plain cylindrical plug gages.

1. Wire type design, above 0.030 to and including 0.510 in. The wire type design consists of a handle with collets on its end for holding wire or pin-type gaging members.

2. Taper lock design, above 0.059 and including 1.510 in. The taper lock gaging member has a taper shank that fits in a correspondingly tapered hole in a hexagonal handle.

3. Reversible or trilock design, above 1.510 to and including 8.010 in. The trilock gaging member has three locking grooves on its end that engage corresponding locking prongs on the end of a hexagonal handle. The gaging member, which may be reversed when it becomes worn on one end, is held in place with a screw through its center.

4. Annular design, above 8.010 to and including 12.010 in. This design consists of a rim and web, bored out in the center to reduce weight, and two ball-crank handles to facilitate handling the tool.

"Go" plug gage members are slightly more than twice as long as

[1] Norbide is the trade name of boron carbide produced by the Norton Company.

"not go" members to distinguish one from the other. Various kinds of taper lock gaging members with handles are shown in Figs. 8.4 to 8.7, inclusive.

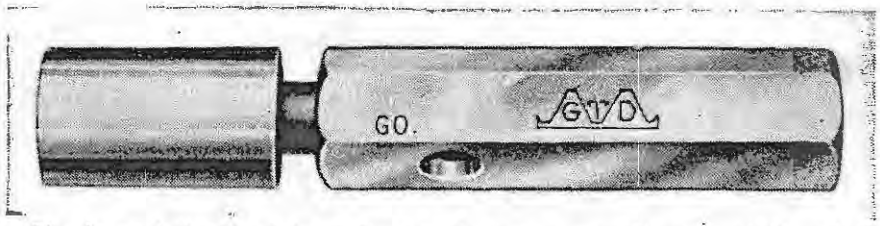


Fig. 8.4 Single-end "go" plain cylindrical plug gage. *Courtesy of Greenfield Tap and Die Corporation.*

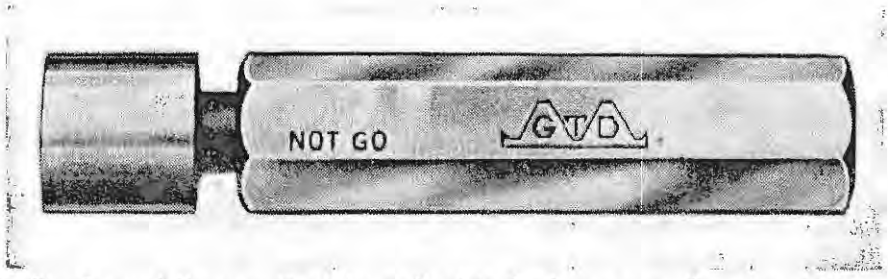


Fig. 8.5 Single-end "not go" plain cylindrical plug gage. *Courtesy of Greenfield Tap and Die Corporation.*

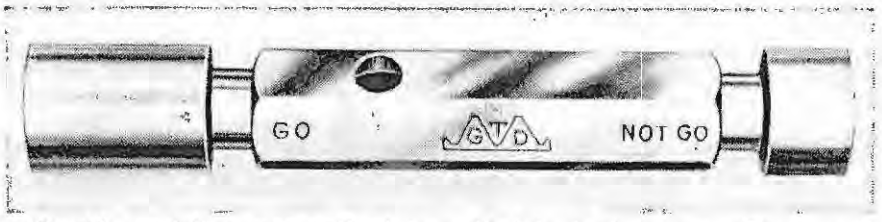


Fig. 8.6 Double-end "go–not go" plain cylindrical plug gage. *Courtesy of Greenfield Tap and Die Corporation.*

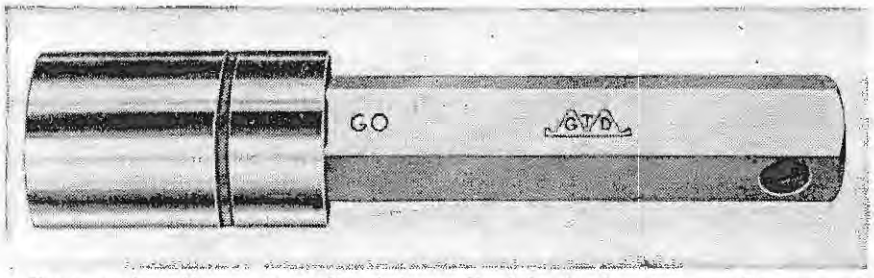


Fig. 8.7 Progressive "go–not go" plain cylindrical plug gage. *Courtesy of Greenfield Tap and Die Corporation.*

A plain cylindrical "go" plug gage may be provided with a pilot to guide it into the hole being measured. This construction consists of an annular groove on the entering end of the gaging member. The pilot guides the gage into the hole automatically by tipping the gage

so that the groove contacts the edge of the hole and raising it, as shown in Figs. 8.8 and 8.9.

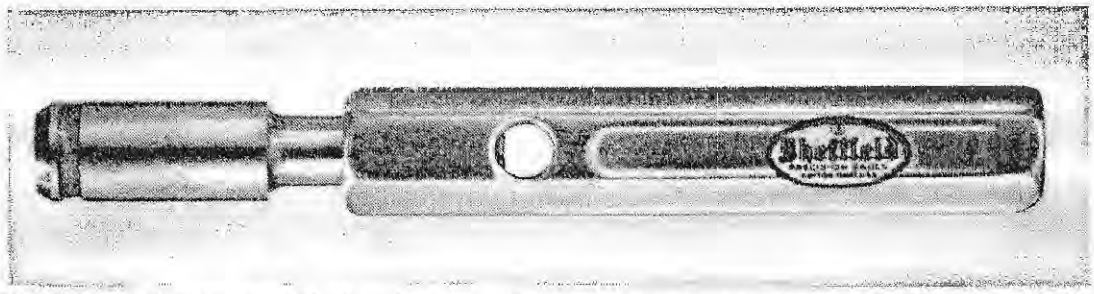


Fig. 8.8 "Guide gage" showing annular groove on entering end. *Courtesy of The Sheffield Corporation.*

Fig. 8.9 "Guide gage" entering hole. *Courtesy of The Sheffield Corporation.*

The AGD-recommended general design for flat plug gages for use in the size range above 1.510 to and including 8.010 in. is illustrated in Fig. 8.10.

An adjustable limit plug gage is manufactured for use in the size range of 2½ to 12 in. Figure 8.11 illustrates models for measuring sizes above 4 in.

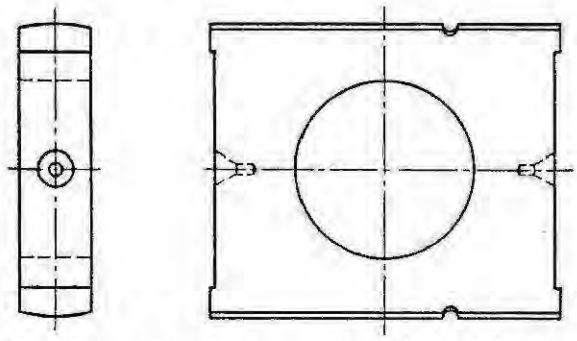


Fig. 8.10 Recommended general design of flat plug gage.

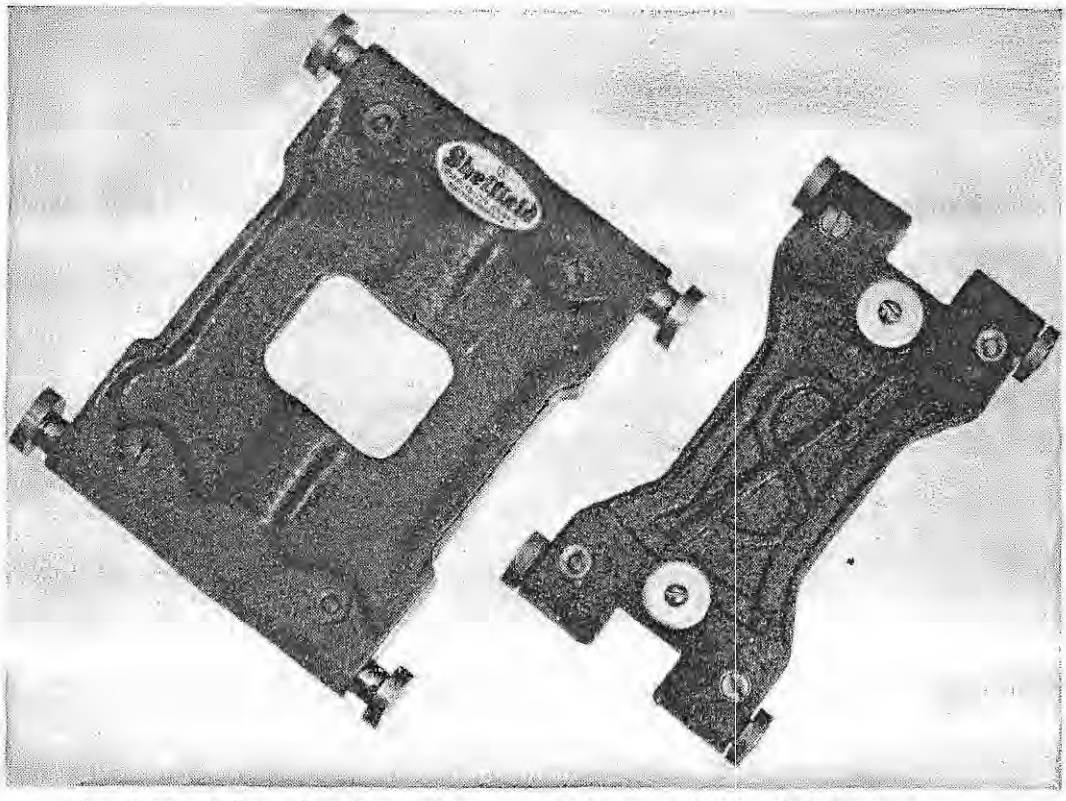


Fig. 8.11 Adjustable limit plug gages. *Courtesy of The Sheffield Corporation.*

Plain Cylindrical Ring Gages

A ring gage is one whose inside measuring surfaces are circular. It may be cylindrical or conical, plain or threaded, or keyed to measure a spline.

A plain cylindrical ring gage is an external gage that is used to measure the diameter of a plain cylindrical shaft. Four AGD standard designs have been adopted for these gages:

1. Plain cylindrical ring gages for the size range 0.059 to and including 0.510 in. may be made by pressing a hardened bushing

into a soft gage body. One piece construction described next, however, is optional for gages in this range.

2. Plain cylindrical ring gages for the size range above 0.510 to and including 1.510 in., and optional from 0.059 to and including 0.510 in., are of one-piece construction.

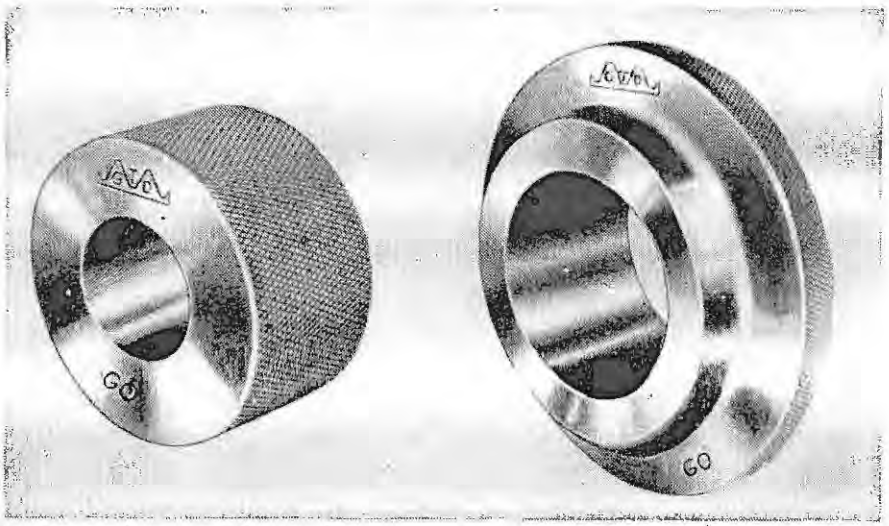


Fig. 8.12 One piece and flanged constructions of "go" plain cylindrical ring gages. *Courtesy of Greenfield Tap and Die Corporation.*

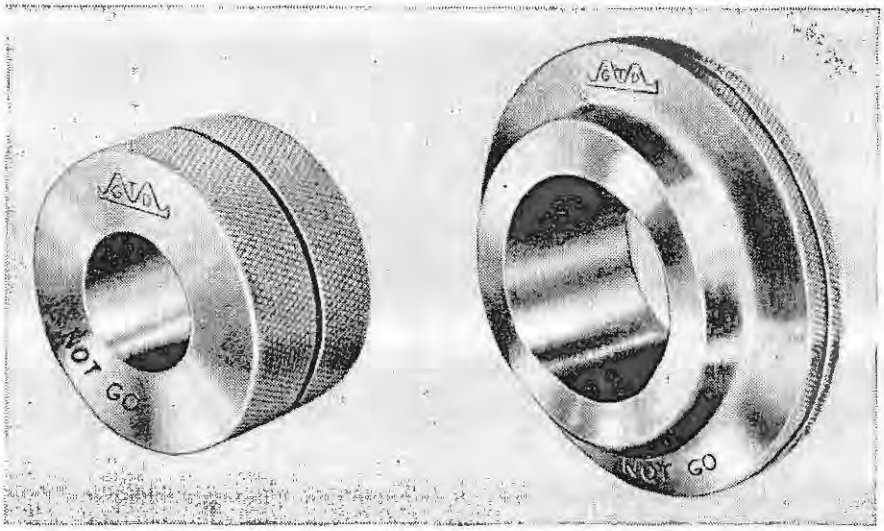


Fig. 8.13 Plain cylindrical "not go" ring gages. *Courtesy of Greenfield Tap and Die Corporation.*

3. Ring gages for the range above 1.510 to and including 5.510 in. are flanged to reduce weight and to facilitate handling.

4. Ring gages for the size range above 5.510 to and including 12.260 in. are flanged and provided with two ball-crank handles as a further aid to handling.

"Go" ring gages are plain, and "not go" gages have an annular groove in the periphery. These are illustrated in Figs. 8.12 and 8.13.

Plain Adjustable Limit Snap Gages

A snap gage is one having inside measuring surfaces arranged to measure diameters, thicknesses, lengths, etc. It may be plain or threaded, and solid, adjustable, or built-up.

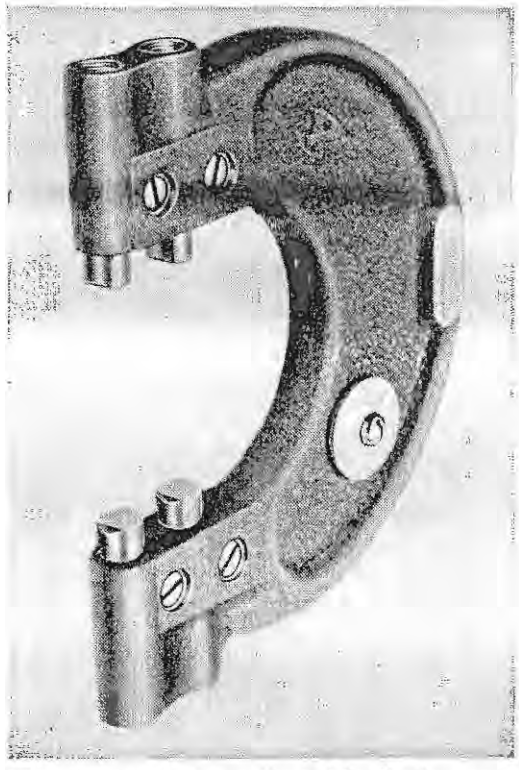


Fig. 8.14 Plain adjustable limit snap gage, model A. *Courtesy of Greenfield Tap and Die Corporation.*

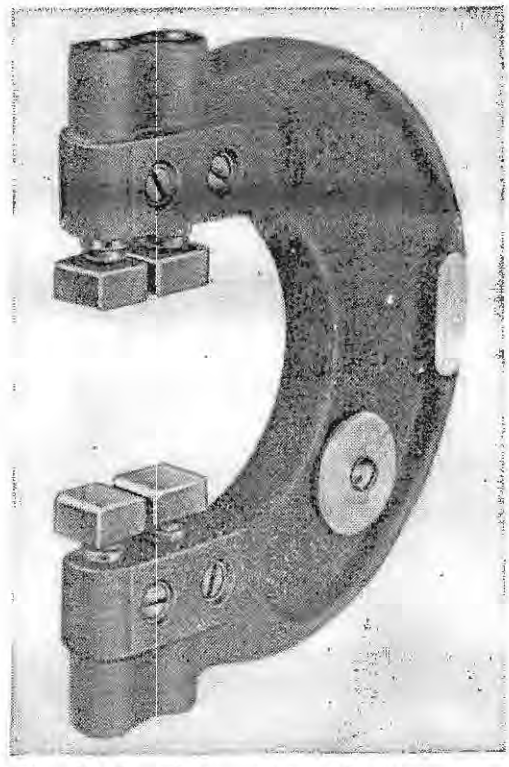


Fig. 8.15 Plain adjustable limit snap gage, model B, with square gaging buttons. *Courtesy of Greenfield Tap and Die Corporation.*

A plain adjustable limit snap gage is an outside caliper type gage that is used to measure external dimensions. It consists of a C-shaped frame with plain gaging members attached to the jaws, one or more pairs of which may be set and locked to any size within the range of the tool. Five styles of AGD plain adjustable limit snap gages have been adopted as standard:

1. Model A, for the size range 0 to 12 in., inclusive, employs four gaging pins in its construction, as shown in Fig. 8.14.

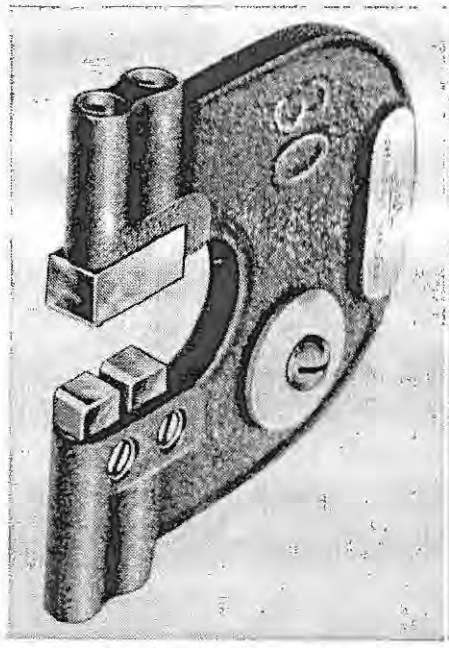


Fig. 8.16 Plain adjustable limit snap gage, model C, with square gaging buttons. *Courtesy of Greenfield Tap and Die Corporation.*

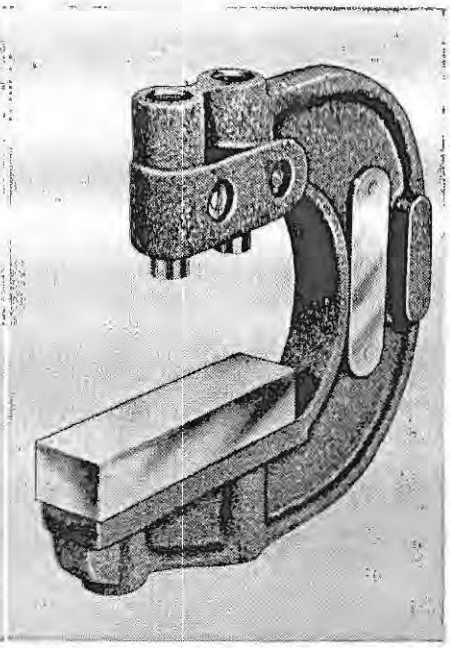


Fig. 8.17 Plain adjustable limit snap gage, model E. *Courtesy of Greenfield Tap and Die Corporation.*

2. Model B, range ½ to 11¼in., inclusive, employs four round or square gaging buttons. The use of square buttons is illustrated in Fig. 8.15.

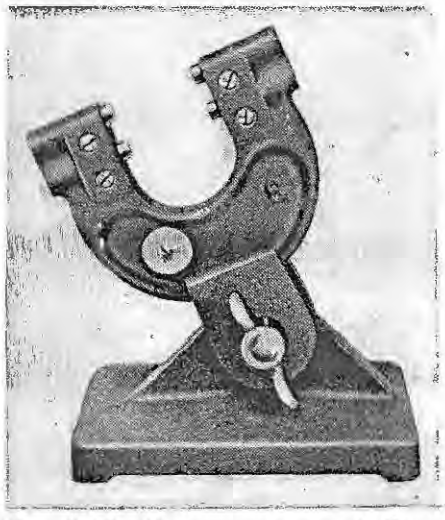


Fig. 8.18 Snap-gage stand. *Courtesy of Greenfield Tap and Die Corporation.*

3. Model C, range 0 to 11⅝ in., inclusive, employs a single block anvil on one jaw, and two gaging buttons, either round or square, on the other. Model C is shown in Fig. 8.16.

4. Model MC, range 0 to 0.760 in., inclusive, is a minature gage having the same anvil and gaging button arrangement as Model C.

5. Model E, range 0 to 5 11/16 in., inclusive, employs two gaging buttons, either square or round, and a single block anvil that extends beyond the gaging buttons as illustrated in Fig. 8.17.

The outer gaging members of an adjustable limit snap gage are set to the maximum limit of the part to be measured, and the inner members are set to the minimum size. The outer members, therefore, form a "go" gage, and the inner members form a "not go" gage that may be used to check both limits of a shaft with the one tool in a single continuous motion.

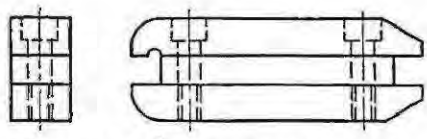


Fig. 8.19 Recommended design for built-up snap gage.

The adjustable snap-gage stand, shown in Fig. 8.18, may be used to hold a snap gage in position, thereby leaving the hands free to manipulate work during inspection operations.

The AGD-recommended design for a built-up snap gage is illustrated in Fig. 8.19. The beveled end of the tool is the "not go" gage.

Adjustable Limit Length Gages

Adjustable limit length gages are used to measure shoulder and over-all lengths of shafts, outside diameters of pulleys, etc. AGD standard gage-head designs consist of four models.

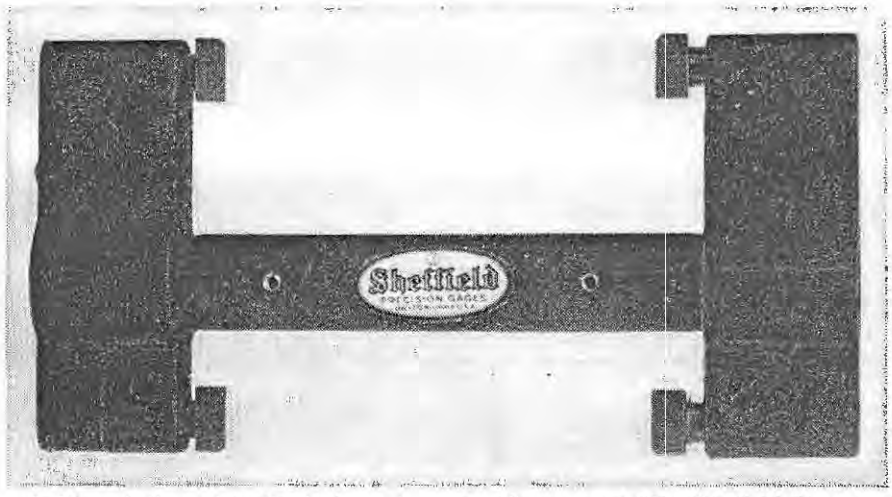


Fig. 8.20 Adjustable limit length gage. *Courtesy of The Sheffield Corporation.*

1. Models KA and KB are double-sided with gaging buttons on opposite sides of the gage head. A double-sided model is shown in Fig. 8.20.

2. Models LA and LB are progressive models with gaging members on the same side of the gage head.

Master Disks

Master disks are designed specifically for setting and checking such measuring tools as adjustable limit snap and length gages, outside micrometer calipers, comparators, etc. They are made to Class

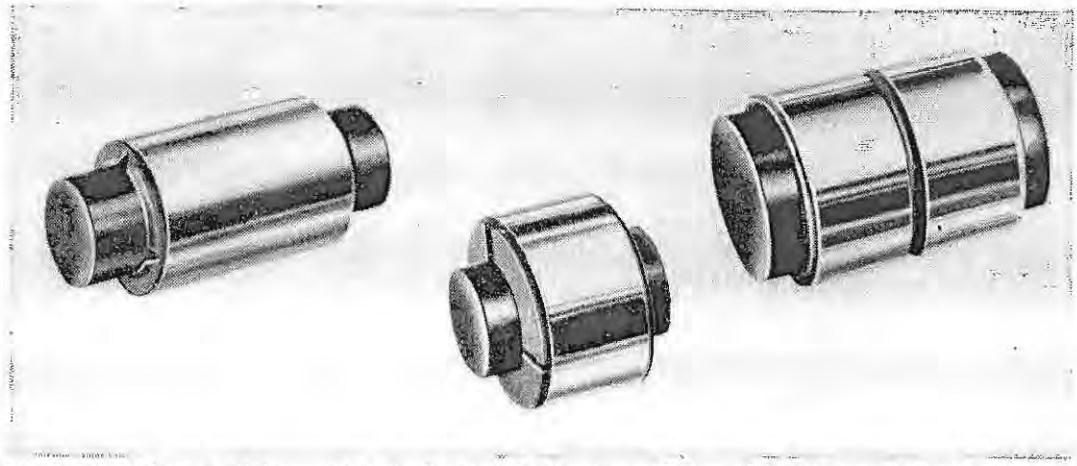


Fig. 8.21 Master disks—styles 1, 3, and 2. *Courtesy of Greenfield Tap and Die Corporation.*

XX, Class X, and Class Y gagemakers' tolerances. The gages are made with an insulating finger grip to prevent the fingers coming in contact with and expanding the tool, and they are made in three styles, shown in Fig. 8.21. Style 1 is a "go" gage, style 2 is a "go–not go" gage, and style 3 is a "not go" gage.

Special Gages

A spline gage is one that has a number of teeth on its gaging surface that correspond in contour, diameter, and spacing with the spline to be measured. Spline ring gages are shown in Fig. 8.22.

An AGD-recommended design for a flush pin gage, used to measure depths of holes, slots, etc., is shown in Fig. 8.23. When this type of gage is in use, the head of the gaging pin is felt with the fingers to determine if the measurement is within specified limits as indicated by the milled surface on the pin.

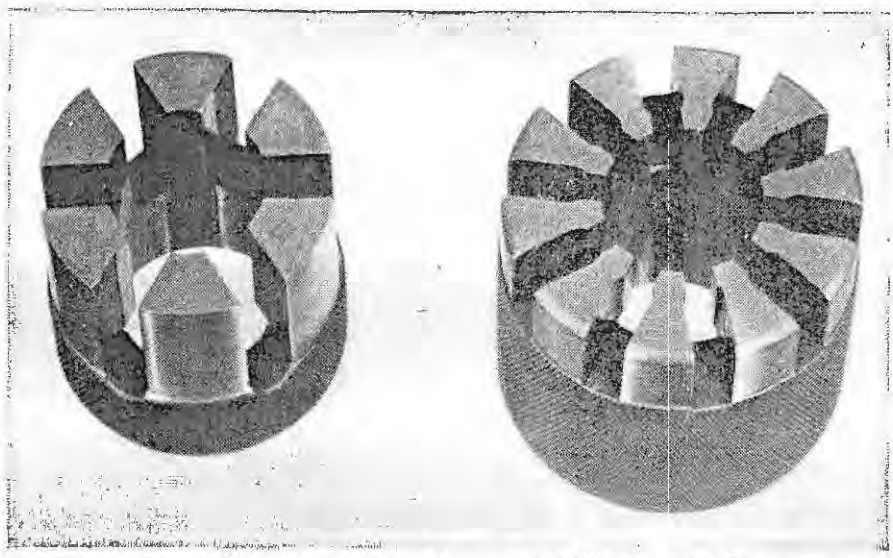


Fig. 8.22 Spline ring gages. *Courtesy of The Sheffield Corporation.*

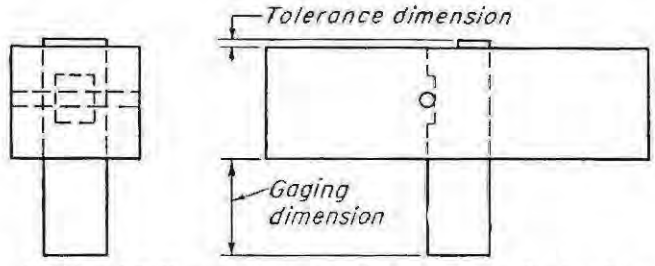


Fig. 8.23 AGD-recommended design for flush pin gage.

Care of Gages

Gages should be used and cared for properly to assure their maximum useful service life. Some suggestions for their use and care follow.

Master, inspection, and working gages should be applied only to the uses for which they are intended; that is, a master gage should be used to check inspection and working gages, an inspection gage should be used to check the finished product, and a working gage should be used to measure the product as it is being manufactured.

A plain cylindrical plug gage should be cleaned, and a thin film of light oil should be applied to the gaging surface before it is used. The work should be cleaned also. Then the gage should be aligned with the hole to be measured and given a forward motion combined with a slight rotation. The "go" gage will enter the hole if the latter

is of correct size, but the "not go" gage will not enter it. Keep the gage moving into and out of the hole, when the fit is close, to prevent seizure of the parts. The same suggestions are applicable to the use of plain cylindrical ring gages.

Do not force a snap gage over work because forcing will cause the tool to pass oversized parts, and it may also spring the frame of the tool. In fact, force should be avoided in any gaging operation as it tends to harm the tool, the work, or both.

A gage should be cleaned after use and prepared for storage. If it is to be stored for a short time only, it should be coated with a rust-preventive oil. If it is to be stored for a long period of time, however, it should be dipped in a molten plastic material designed as a protective coating for tools.

QUESTIONS

1. To what does the abbreviation AGD marked on some gages refer?
2. What difference is there in the dimensional accuracy, finish, and use of (*a*) master gages, (*b*) inspection gages, and (*c*) working gages?
3. What kind of limit gage controls the following dimensions: (*a*) the minimum size of a hole, (*b*) the maximum size of a hole, (*c*) the minimum size of a shaft, and (*d*) the maximum size of a shaft?
4. Plain cylindrical plug and ring gages are made in five classes of tolerance as follows: Class XX, Class X, Class Y, Class Z, and Class ZZ. Which is the most accurate? Which is the least accurate? What is the recommended application for each class?

9

INDICATING GAGES AND COMPARATORS

Indicating gages and comparators are instruments that compare work with a standard and indicate variations in size on a graduated scale or with tolerance signals. Sometimes, the standard is built into the gage; usually however, the instrument must be set to the required dimension with the aid of precision gage blocks, a master gage, or a setting gage. The work may be tested with one or more gaging members on the instrument; and variations in size from the standard are either amplified, so that they may be read on a graduated scale, or they produce a signal showing that the product is inside or outside of the limits specified for it. Amplification of variations in size may be accomplished by mechanical, optical, air, or electrical systems; and electrical gages may be designed to sort the product into various classes automatically.

Dial Indicators

A dial indicator is a measuring instrument that consists of a graduated dial and an indicating hand, illustrated in Fig. 9.1, a contact point mounted on a spindle, and a geared amplifying movement, shown in Fig. 9.2. The amplifying mechanism magnifies slight dis-

placements of the contact point and spindle and transmits them to the indicating hand so that variations in size may be read on the dial. The movement of a dial indicator, which is built like a fine watch with precision-cut gears and jeweled bearings to secure accuracy, is housed in a drawn or die-cast case. The dial is protected with a glass or plastic cover, and the back of the case is closed with a metal cover. Contact points for dial indicators are made of hardened steel for ordinary service, but they may be tipped with Stellite or similar cast alloys, cemented carbide, Norbide, synthetic sapphires, or diamonds for use in severe service.

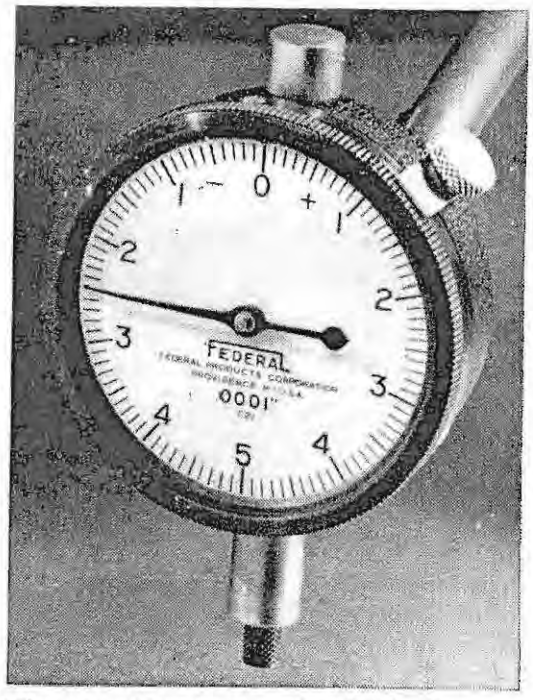


Fig. 9.1 Front view of a dial indicator. *Courtesy of Federal Products Corporation.*

American Gage Design standards have been adopted by the manufacturers, distributors, and users of these tools to provide interchangeability in the styles and dimensions of their mountings, and uniformity in the range of spindle travel and the setting for indicator hands. The indicator spindle travel equals 2½ revolutions of the indicating hand, and the hand is set at the 9-o'clock station when the spindle is in the rest position to permit measuring on both the minus and the plus sides of zero without first making a full or nearly full revolution of the indicating hand.

Dial indicators are made in models that measure in 0.001, 0.0005, 0.00025, 0.0001, and 0.00005 in. Standard dial numbering is furnished in two types: continuous dials are numbered to read continuously from zero in a clockwise direction, balanced dials are numbered to read minus on the counterclockwise side of zero and plus on the clockwise side. Dials with other markings for special applications are available. Dials are attached to knurled bezels or

rings on the rim of the case so that zero, or any other graduation, may be set to agree with the position of the indicating hand.

Dial indicators may be equipped with tolerance hands—that is, with two hands which may be set from outside of the dial cover to mark tolerance limits for "go–not go" inspection—with special stems

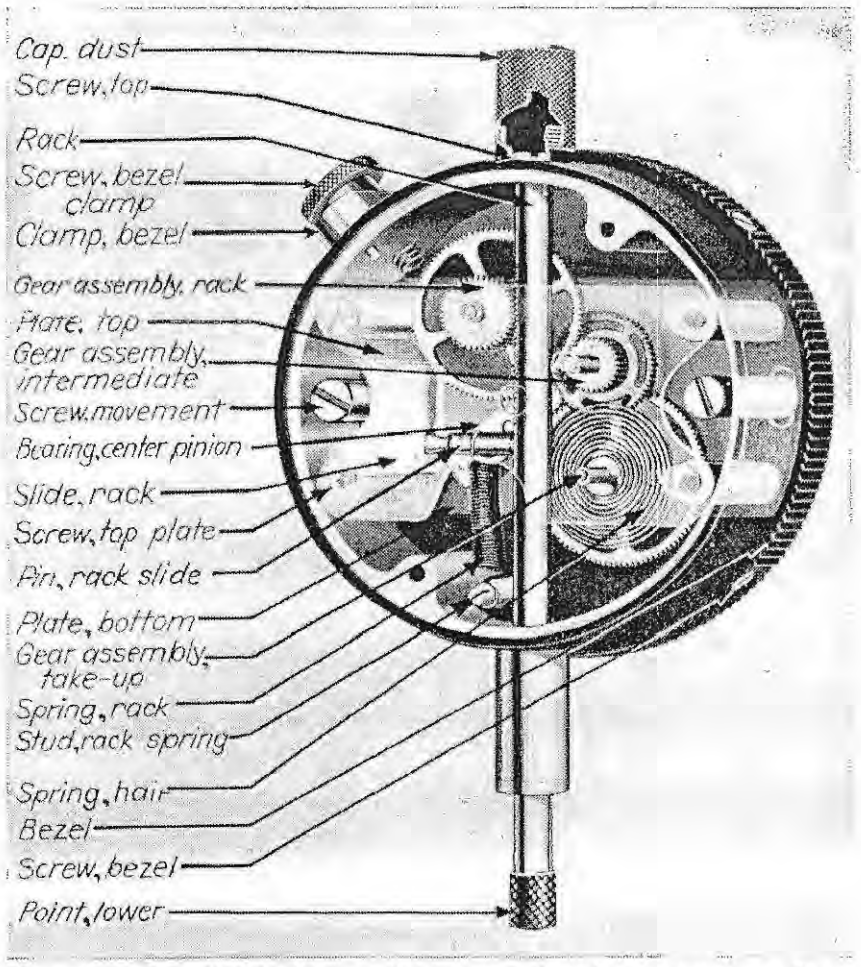


Fig. 9.2 Interior of a dial indicator from rear showing movement for amplifying variations in workpiece dimensions. *Courtesy of Federal Products Corporation.*

and contact points, and with attachments for measuring holes, right-angle surfaces, and other applications.

Dial indicators may be combined with a variety of supporting and gaging members to produce standard and special instruments for external, internal, height, depth, and similar measurements. Some of these tools are classed as test indicators, others as gages, and still others as comparators; however, there is no clear-cut dis-

tinction as to the tools that should be classed in each group. Some tools have self-contained reference surfaces, and others must be set with a master gage to prepare them for use.

Dial Test Indicators

Dial test indicators are used extensively to test the alignment of machine members, chucks, vises, and other fixtures to ensure their

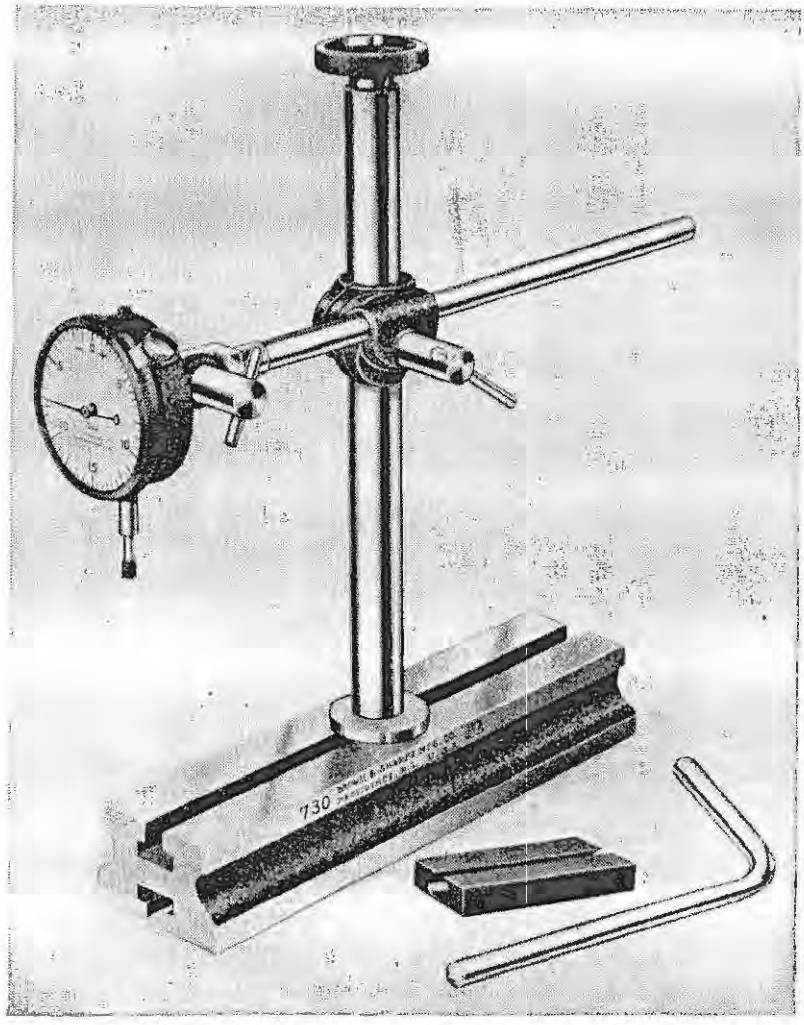


Fig. 9.3 Dial test indicator. *Courtesy of Brown & Sharpe Mfg. Co.*

accuracy prior to production and to check the dimensional accuracy of products. The dial test indicator, illustrated in Fig. 9.3, has a rectangular iron base, a large-diameter tubular upright for rigidity, a sliding swivel, an arm that is adjustable as to height and angle, and a dial indicator. The dial indicator regularly furnished with this

tool has a spindle movement of 0.003 in. and a balanced dial that is graduated to read by 0.0005 in. Hole attachments, base stops, and a wide variety of contact points are available to adapt these indicators for an extensive range of inspection operations.

A similar dial test indicator is designed with a permanent-magnet base by which it may be mounted on vertical and other surfaces where the tool described in the preceding paragraph cannot be used conveniently.

Dial indicator attachments are available for use with surface gages and vernier height gages to adapt them for use as dial test indicators. An attachment consists of a dial indicator and a rod or bar for affixing it to the tool on which it is to be used.

Dial Caliper Gages

Outside and inside caliper-type indicating gages are fast and convenient tools for use in checking outside and inside dimensions on work when tolerances are not close. A gage of this type has one handled arm with a dial gage attached to it, and one movable arm which is pivoted on the handled arm. The movable arm is in contact with the measuring point of the dial gage so that variations in its setting may be read on the dial. These calipers may be made with arms of different lengths and of odd shapes to clear obstructions on the work.

Indicating Snap and Hole Gages

An indicating snap gage is illustrated in Fig. 9.4. The dial indicator, which is mounted at the top of the tool, may be set in any position convenient for reading the gage. A guard at the top of the frame protects the indicator when the tool is laid on a work bench, and an insulated finger grip prevents expansion of the frame from bodily heat. An adjustable lower anvil permits each gage to be used to cover a range of dimensions, and five sizes of this gage will measure all dimensions from 0 to 6 in.

Portable thickness gages, similar in principle to the indicating

snap gage, are useful for measuring various kinds of sheet materials, and they are adaptable to gaging small products. These tools may be obtained with contact pressures suited to measuring different kinds of compressible materials.

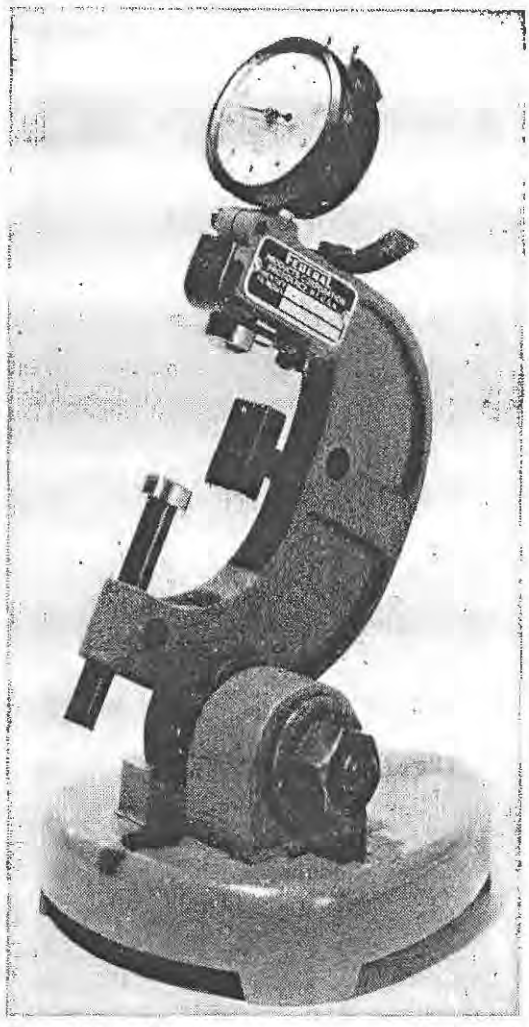


Fig. 9.4 Dial snap gage with bench stand. *Courtesy of Federal Products Corporation.*

The essential parts of the hole gage, illustrated in Fig. 9.5, are a dial indicator and a gage head. The gage head has a single reference contact on the bottom side, and a sensitive contact and two springloaded equalizing contacts on the top. The standard reference and sensitive contacts furnished with this instrument are polished diamonds; however, boron carbide contacts can be furnished on request. The reference contact is mounted on an interchangeable extension, except in the smallest model, and several extensions are required to cover the range of sizes that may be measured with any given model of the tool.

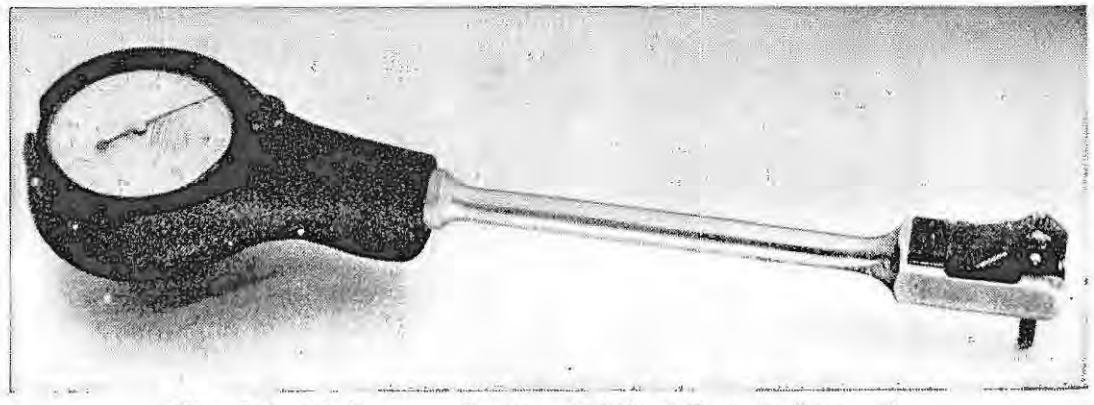


Fig. 9.5 Hole gage. *Courtesy of Federal Products Corporation.*

Indicating Micrometer

The indicating micrometer, shown in Fig. 9.6, combines the uniform contact pressure of a dial indicator and the accuracy of a micrometer screw in an instrument that may be used as a measuring tool or as a comparator gage. It eliminates the chance of errors, due to variations in measuring pressure, that occur with ordinary micrometers; and it saves time in making repetitive measurements because the anvil is retracted with a push button to permit insertion

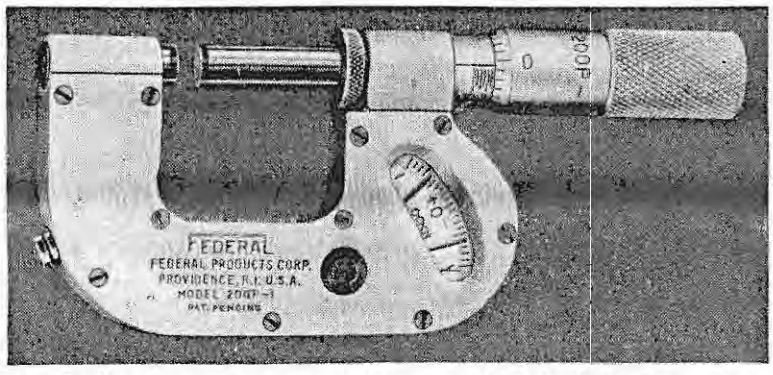


Fig. 9.6 Indicating micrometer. *Courtesy of Federal Products Corporation.*

and removal of work. Thousandths of an inch are read on the barrel and thimble of this tool and ten-thousandths of an inch on the dial indicator. The dial indicator, it should be noted, is furnished with tolerance hands.

Dial Depth Gage

A dial depth gage is designed to measure depths of holes, slots, and shoulders below a reference surface. The tool consists of a dial indicator, having a measuring range of 1 in., which is mounted on a depth-gage head. Interchangeable contact points furnished with the tool, give it three measuring ranges of 0 to 1, 1 to 2, and 2 to 3 in.

Dial or Mechanical Comparators

Dial comparators are instruments that measure thicknesses and outside diameters. In general, these tools consist of a base on which a reference table or anvil is mounted, a column that rises from the rear of the base, and a vertically adjustable gage head which is mounted on the column. The gage head is set, with reference to the

table or anvil, to measure any size within the capacity of the instrument by using precision gage blocks, setting gages, or master gages; and it indicates variation from the size to which it is set on a dial gage.

The dial comparator, shown in Fig. 9.7, is a supersensitive instrument of high precision. Its dial indicator is graduated to read

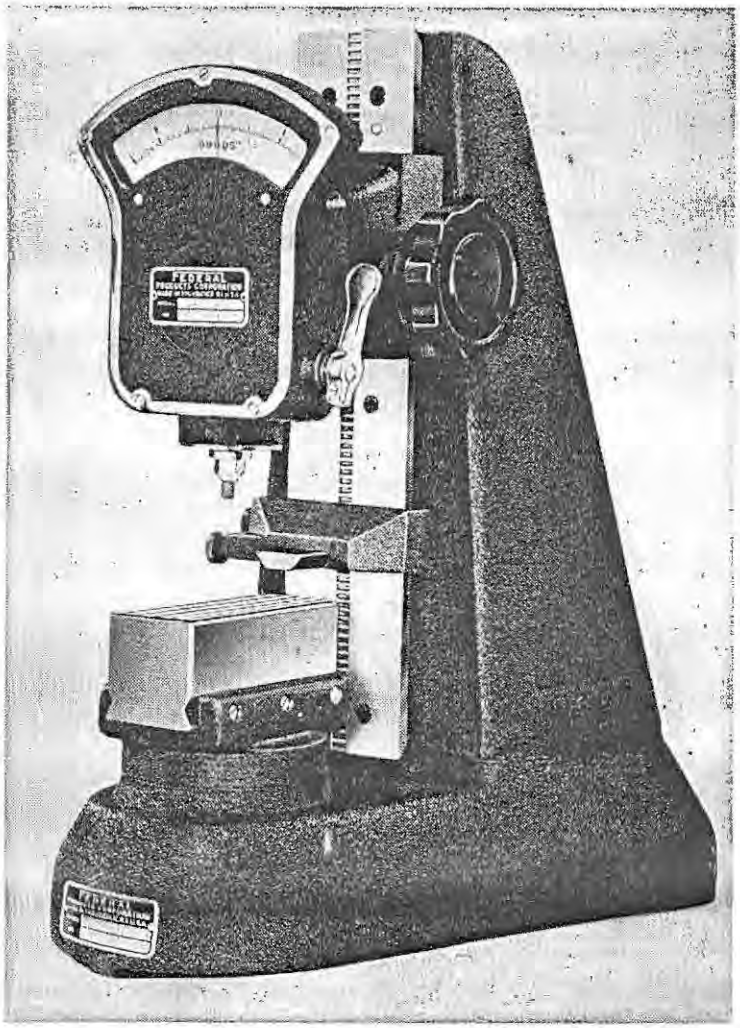


Fig. 9.7 Supersensitive comparator. *Courtesy of Federal Products Corporation.*

0.00005 in., and it has a total range of 0.003 in. The balanced dial is marked to read ± 0.0015 in. The tool has a maximum vertical capacity of 3.750 in. from its diamond-tipped sensitive contact to its lapped anvil.

One dial comparator combines an 0- to 1-in. micrometer head and a dial indicator in its gaging unit. The micrometer head has a range of 0 to 1 in., and its large diameter thimble is graduated to

read directly to 0.0001 in. The dial indicator has a range of 0.008 in., and its balanced dial is graduated to read ±0.004 in. by 0.0001 in. The sensitive contact on this tool is diamond-tipped; the reference anvil is ground and lapped with one side smooth and the other side serrated; and the maximum vertical capacity of the instrument

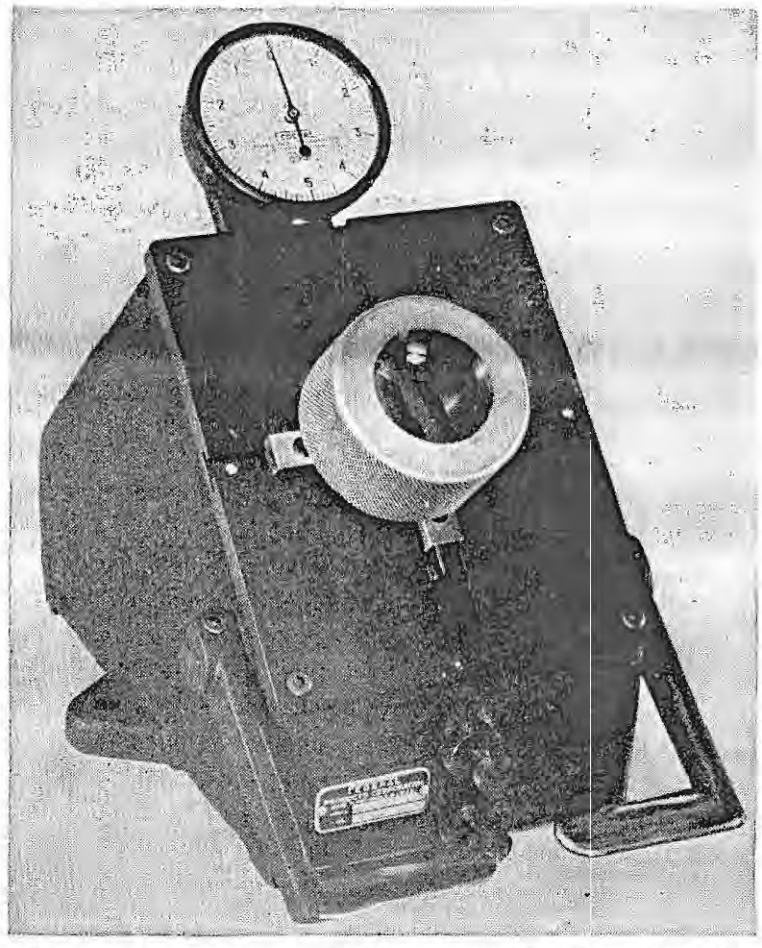


Fig. 9.8 Bench gage for measuring inside or outside diameters. *Courtesy of Federal Products Corporation.*

from sensitive contact to reference anvil is 8 in. Gage blocks measuring whole inches only are required to set this instrument because of the micrometer head that is incorporated in its construction.

The bench gage, illustrated in Fig. 9.8, is a dial comparator that is designed for inspecting either inside or outside diameters. The contact points are retractable while the workpiece is placed in position by pressing on either lever at the front of the gage. Pressure of the contacts on the workpiece is adjustable to the job so that thin-walled parts will not be distorted. Contacts are available in either

a 'T' arrangement or a V arrangement. In the 'T' arrangement, one contact acts as a centralizer, and the other two measure the diameter of the work. The centralizing contact of this arrangement may be removed for measuring holes from 0.187 in. to 0.3125 in. In the V arrangement, two locating and one sensitive contact are used, and the distance from the sensitive contact to the chord between the locating contacts is measured. A special dial indicator is used to compensate for this condition and to permit actual variations of the diameter to be read on the dial. Both the T plate and the V plate three-jaw contact gages have a range of 0.3125 to 3.375 in. for inside measurements and 0 to 3 in. for outside measurements.

Visual Gage

The Visual Gage, illustrated in Fig. 9.9, is an instrument that magnifies the displacement of a contact point and spindle by means of a mechanical reed mechanism and a light beam lever arm so that the amount may be read on a graduated scale. The reed mech-

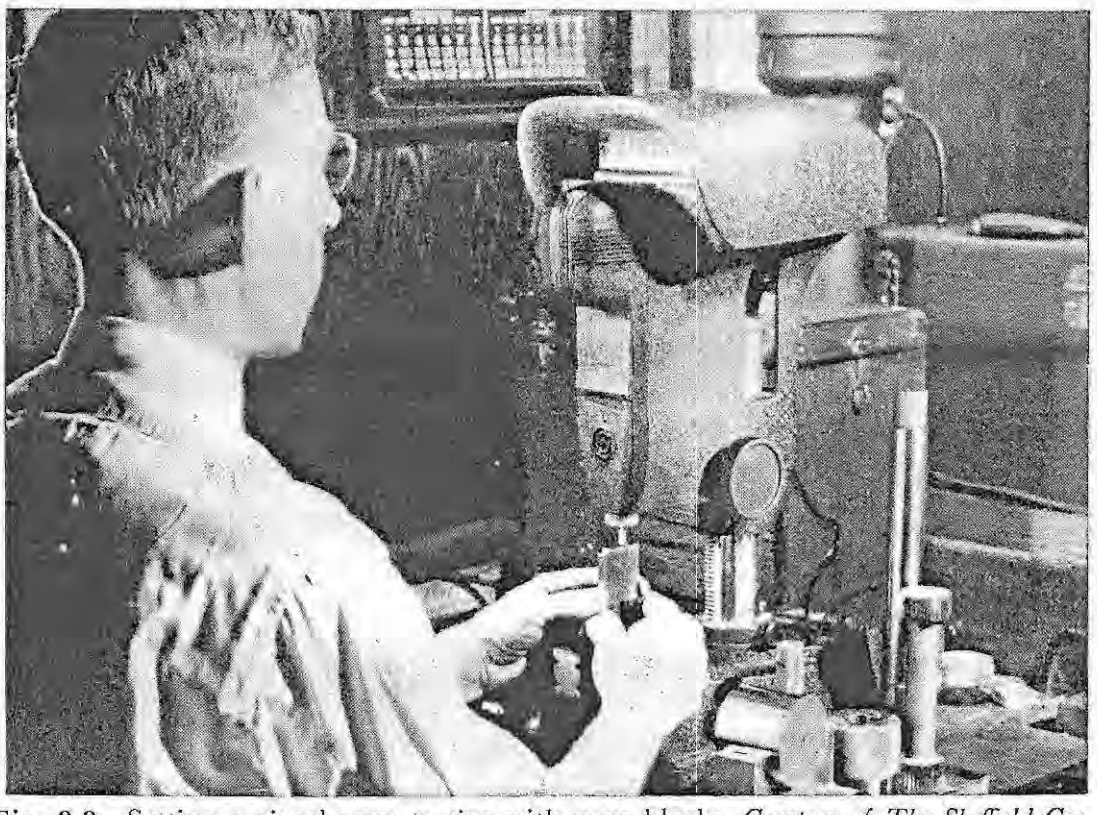


Fig. 9.9 Setting a visual gage to size with gage blocks. *Courtesy of The Sheffield Corporation.*

anism, shown in Fig. 9.10, consists of a fixed block, attached to the gage-head case, and a movable block. These blocks are joined by two horizontal reeds. Two vertical reeds, one being attached to the

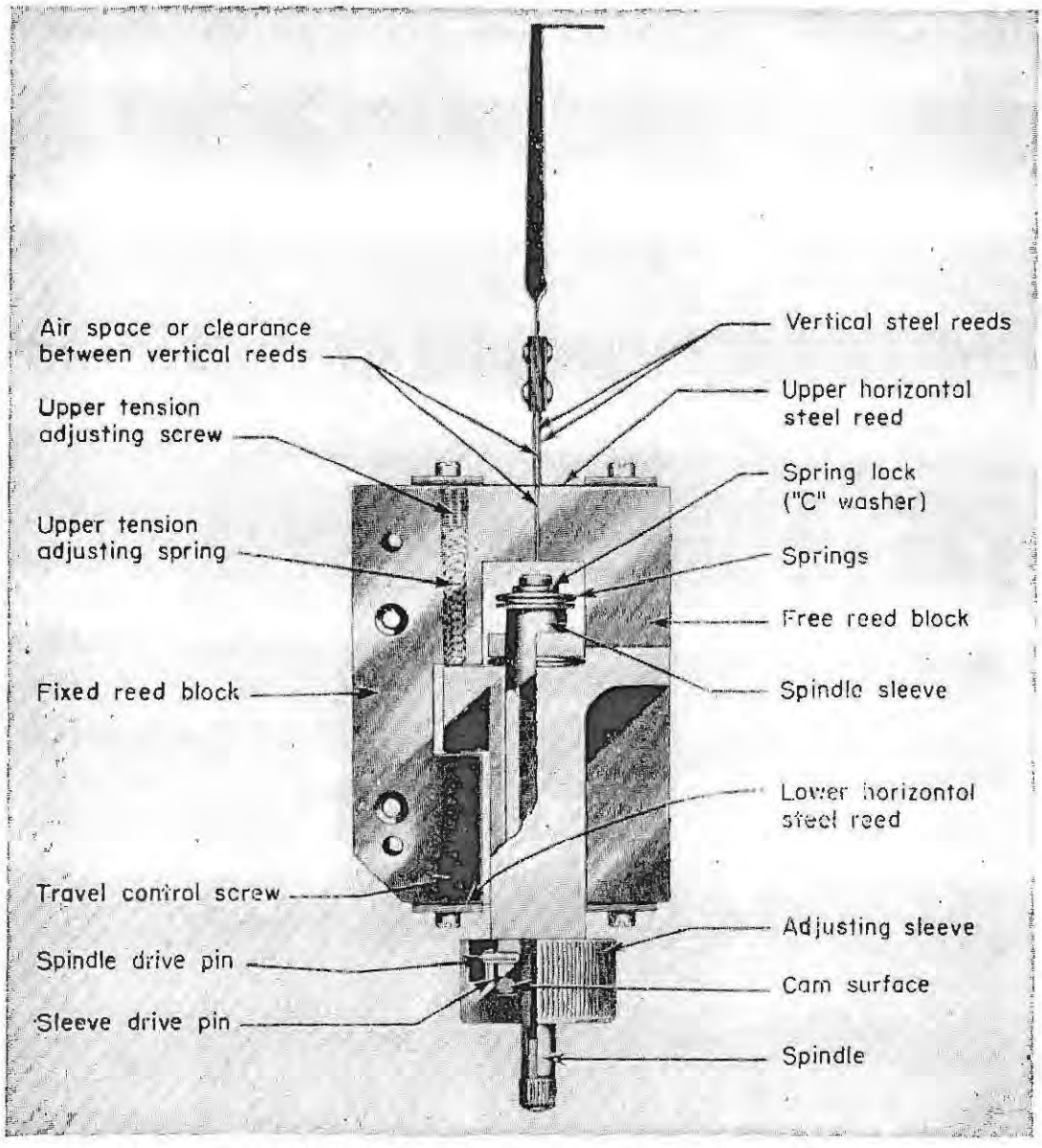


Fig. 9.10 Principle of the Reed mechanism. *Courtesy of The Sheffield Corporation.*

inner side at the top of each block, are joined together at their upper ends.

The gaging spindle is integral with the floating block. When the spindle and block are moved upward by a gaging operation, the horizontal reeds deflect, and the vertical reed on the floating block tends to slip past the corresponding reed on the fixed block. The

vertical reeds, however, bend in an arc because they are joined at their upper ends. A target, which is an extension of the vertical reeds, swings through a larger arc which is proportional to the movement of the spindle. The target interrupts a beam of light, and the resulting shadow is magnified by a system of lenses and projected onto a scale in the head of the instrument.

Various models of the Visual Gage give amplifications of 500 to 1, 1,000 to 1, 2,000 to 1, 5,000 to 1, 10,000 to 1, and 20,000 to 1; Their respective graduations are read 0.001, 0.0001, 0.00005, 0.000025, 0.000010, and 0.000002 in.

To set up a Visual Gage for use:

1. Light the lamp by operating the switch at the back and left side of the base.
2. Loosen the screw that binds the gage head to the column. This screw is located on the left side of the gage head.
3. Raise the gage head with the rack-and-pinion adjustment to clear the master gage. The knob for making this adjustment is on the right side of the gage head.
4. Place the master gage on the anvil and move it under the spindle.
5. Adjust the gage head with the rack-and-pinion mechanism until the contact point bears on the master gage and the edge of the shadow is near zero on the scale. Bind the gage head in place.
6. Set the spindle with the adjusting sleeve until the edge of the shadow falls exactly on zero. The gage is ready for use.

Provision is made for rotating the gage head on the column of the Visual Gage so that work which is set up on a surface plate beside it may be inspected.

Attachments are available for use with the Visual Gage to check screw threads, tapers, concentricity, and inside diameters on work.

Electrical Gages and Comparators

An electrical gage or comparator is an instrument that measures small dimensional variations from the standard size of work by

altering the voltage characteristic of an electrical circuit. The variation in voltage can be amplified and measured as a dimension on an indicating meter, or it can be used to open and close switches that operate signaling devices or automatic sorting mechanisms. Electrical comparators possess many advantages.

1. Different ranges of amplification for measuring different classes of work may be obtained in a single gage.
2. Any degree of amplification required for either industrial or laboratory applications may be obtained. Measurements in millionths of an inch are possible.
3. Gage heads may be set up at places remote from the amplifier and meter.
4. Gage heads may be used as portable gages.
5. Gage heads are adaptable to multiple gaging setups.

Several electrical comparators that operate on different principles, or which have other distinguishing features, are described in the following accounts.

Electrolimit Comparator

The Pratt and Whitney Gage Block Comparator, shown in Fig. 9.11, is an Electrolimit external comparator that is specifically designed to check the accuracy of precision gage blocks. One division on the scale of the meter that is furnished with this instrument reads 0.0000025 in. Other models of the instrument have scale divisions that read from 0.001 to 0.000001 in.

An Electrolimit external comparator consists of a base, column, gage head and bearing bracket, and indicating meter. The base, of ribbed cast iron, is designed to support the column with the rigidity necessary for extreme accuracy in gaging. The chromium-plated anvil is of heat-treated alloy tool steel. The chromium-plated, hollow steel column may be rotated through 360 deg so that the gage may be set up on a surface plate and the gage head positioned to measure work placed beside it. The Electrolimit gage head and bearing bracket may be positioned vertically on the column with an elevating screw.

Two styles of meter are available for use with the Electrolimit comparators. One style, shown in Fig. 9.11, is contained in a portable cabinet that houses the power unit and the magnification and zero adjustments. The other style is mounted on the gage head; and

Fig. 9.11 Electrolimit gage-block comparator. *Courtesy of Pratt & Whitney; Photo from Pratt & Whitney Division, Niles-Bement-Pond Co.*

the power unit, and the magnification and zero adjustments are contained in the base of the instrument.

The Electrolimit external comparator is set to size by placing a stack of precision gage blocks or a master gage on the anvil and lowering the gage head until the contact point bears on the gage and the pointer on the meter reads nearly zero. Exact setting to zero is made with the zero adjustment on the instrument.

The Electrolimit universal circuit consists of three electrical units:

an electrical gage head, a power unit, and a meter. Magnification of movement of the contact point and spindle is obtained by unbalancing a bridge circuit made up of two inductances and two capacitors. The inductances are arranged in the gage head so that a steel armature, which is actuated by the gaging spindle, unbalances the bridge circuit. The power unit contains the two capacitors, stepdown transformers, and the magnification and zero controls. The magnification control is adjustable with a screw driver, and the zero control is adjustable with a knob on the front of the meter cabinet. The indicating meter operates on direct current provided by a copper oxide rectifier in the power circuit.

Other Electrolimit comparators and gages consist of an internal comparator, a height gage, snap gages, and mill gages.

Electronic Production Measuring and Inspection Equipment

Brown and Sharpe electronic production measuring and inspection equipment consists of an amplifier, an external comparator, an internal-comparator attachment, a gage-head cartridge, an elec-

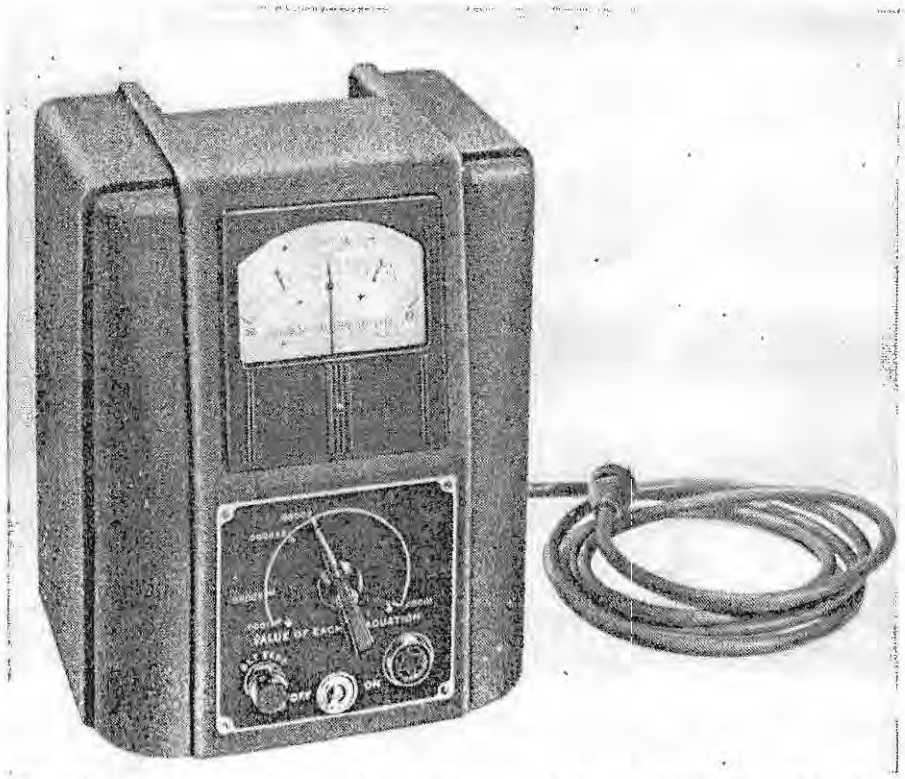


Fig. 9.12 Electronic amplifier. *Courtesy of Brown & Sharpe Mfg. Co.*

tronic caliper, and a signal light attachment in separate units that may be combined in different arrangements to adapt them to specific inspection requirements. This equipment employs the Wheatstone-bridge circuit in the form of a strain gage to provide a means for making external and internal measurements varying from 0.0001

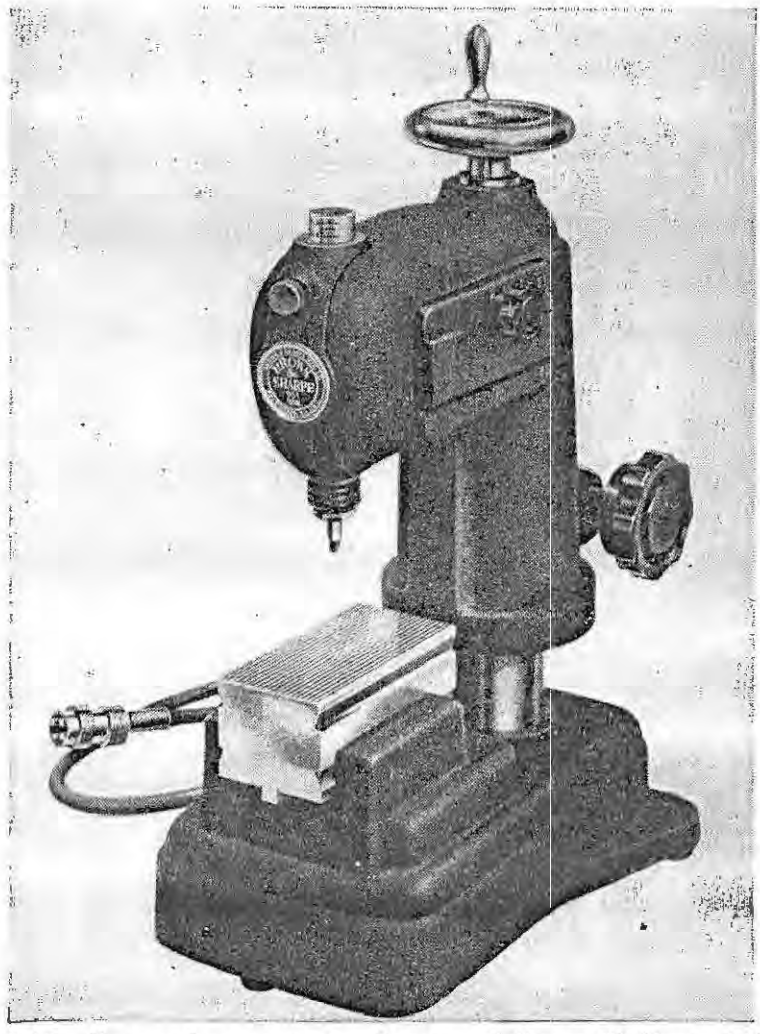


Fig. 9.13 External comparator. *Courtesy of Brown & Sharpe Mfg. Co.*

to 0.00001 in. The amplifier, shown in Fig. 9.12, magnifies movements of contact points on comparators and gaging devices used with it from 1,800 to 18,000 times through electronic means. Positioning the graduation selector enables measurements to be made in units of 0.0001, 0.00005, 0.000025, 0.00002, or 0.00001 in. A set zero control permits the meter pointer to be positioned at zero when setting up instruments.

The external comparator, illustrated in Fig. 9.13, consists of a base, a reversible anvil having one broad and one narrow gaging surface, a column, a gage head with a diamond-tipped measuring point, and an enclosed elevating screw. An adjustable pressure device controls pressure of the measuring point on the work. The range of this instrument is from 0 to 4 in.

The internal-comparator attachment, for measuring inside diameters, replaces the anvil on the external comparator. It permits a

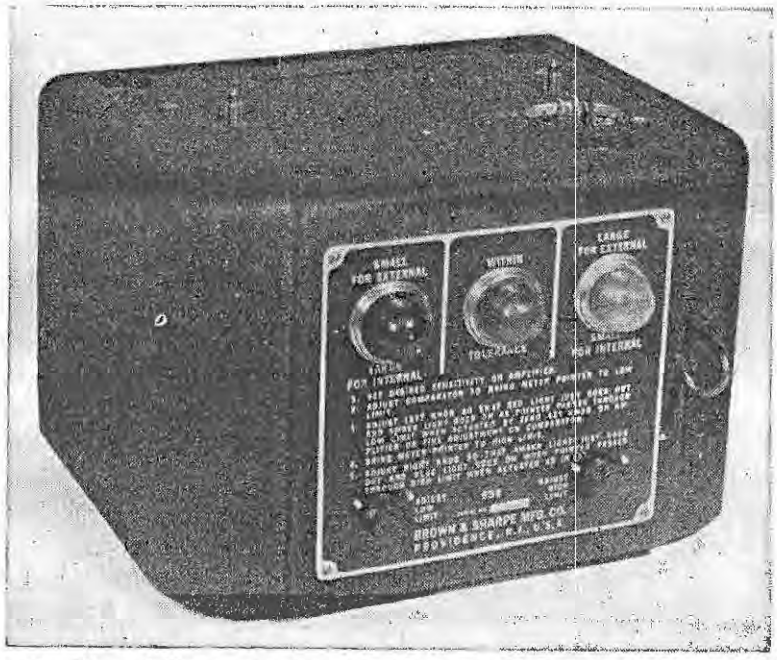


Fig. 9.14 Signal-light attachment. *Courtesy of Brown & Sharpe Mfg. Co.*

range of measurements from ½ to 2 in. through the use of interchangeable plugs. The measuring point of the attachment is tipped with cemented carbide to reduce wear.

The gage-head cartridge is used to connect gages, fixtures, and sorting devices with the amplifier.

The signal-light attachment, illustrated in Fig. 9.14, attaches to the bottom of the amplifier. Three lights in back of red, amber, and blue lenses are used for gaging of the "go–not go" type. The amber light glows if the workpiece is within limits, the red light if it is too small, and the blue light if it is too large.

The electronic caliper consists of a caliper body and four interchangeable jaws that provide for a range of measurements of 0 to

1, 1 to 2, 2 to 3, and 3 to 4 in. Measuring faces of the caliper are of cemented carbide to resist wear.

This electronic measuring equipment may be used with multiple gaging fixtures, so that several measurements may be indicated simultaneously, or with special automatic inspecting and sorting machines designed for rapid production inspection of work.

Electronic Comparator

The Federal electronic comparator consists of a base, column, gage head, indicating meter, limit light, elevating screw, and amplifier. The indicating meter and limit light are attached, at the left and right sides, respectively, to the gage head. The amplifier is a separate unit, and it can be set wherever convenient. It gives four magnifications, using coarse and fine scales on the meter, and provides dimensional readings from 0.003 to 0.00001 in. The gaging head, meter, and amplifier are available separately for adaptation to the user's requirements.

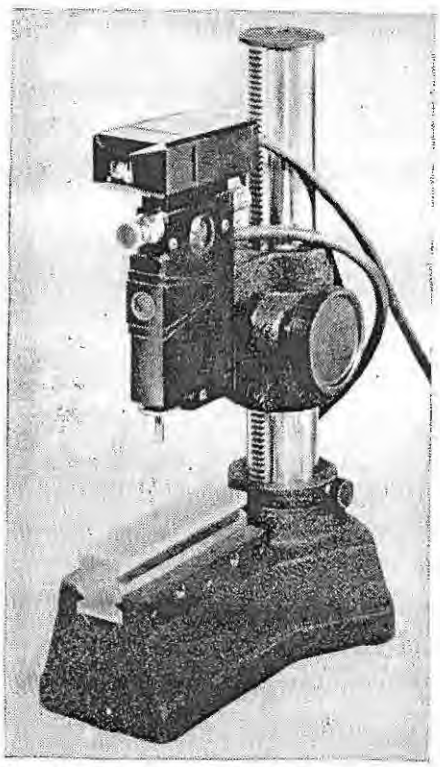


Fig. 9.15 Electrichek electric gage and limit comparator. *Courtesy of The Sheffield Corporation.*

Electrical Comparator Gage

The DoAll electrical comparator gage is made in three models that differ in the magnification which they provide, and each model has four ranges; therefore, a total of 12 ranges giving dimensional readings from 0.001 to 0.000001 in. is obtainable with this line of instruments. The gage head is removable for use in special setups. The amplifier and meter, normally housed in the base of the instrument, may be obtained in a separate cabinet; and multiple amplifier and meter units are available for use when several dimensions are to be gaged simultaneously.

Electrical Gage and Limit Comparator

The Sheffield Electrichek, illustrated in Fig. 9.15, is a limit-type comparator. The gage employs the reed mechanism, described earlier, to operate a needle instead of a target. The elements of the Electrichek gage head are shown in Fig. 9.16. The needle, at the extreme ends of its swing, breaks an electric contact with a terminal

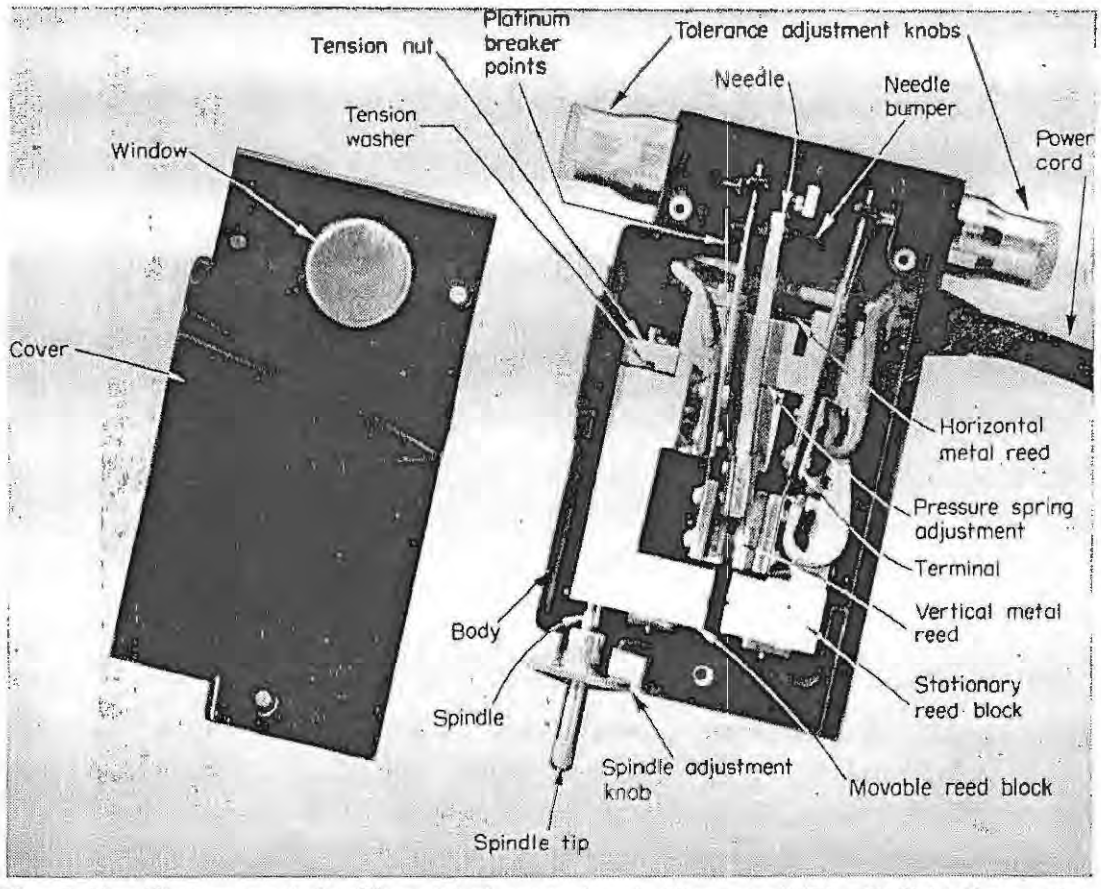


Fig. 9.16 Elements of the Electrichek gage head. *Courtesy of The Sheffield Corporation.*

which is connected with a red signal light on one side, and with a second terminal connected with a green signal light on the other side. The positions of these terminals are set with two micrometer adjusting screws to control the upper and lower limits of the tolerance zone. Two master gages, representing minimum and maximum dimensions of the workpiece, are used to set the terminals so that the red light shows when the piece is undersize, the green light shows when it is oversize, and an amber light shows when it is within tolerance limits.

Multiple Inspection Electrical Gages

The Sheffield Multichek Electrigage, shown in Fig. 9.17, is a multiple electrical gage that is designed to check ten dimensions simultaneously, including five diameters, three groove locations,

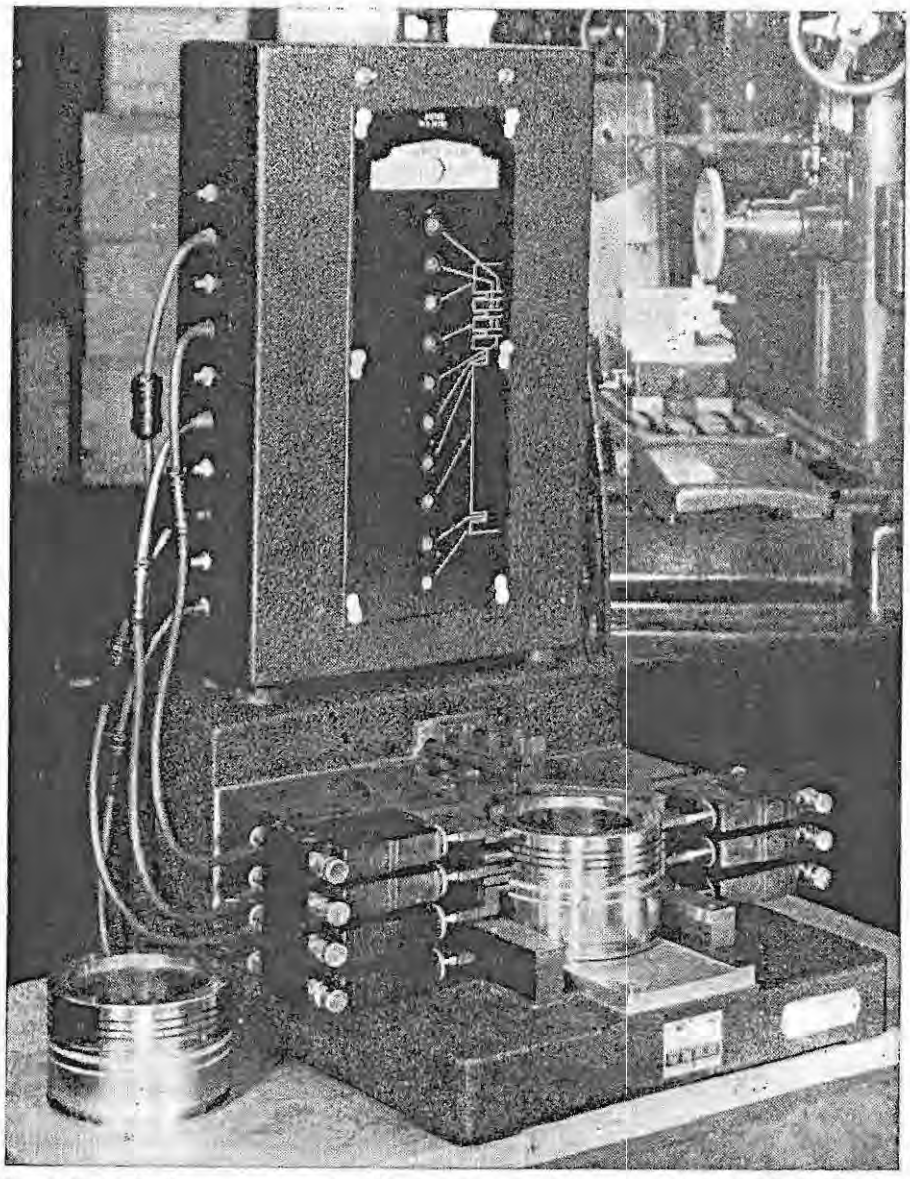


Fig. 9.17 Multichek gage for checking pistons. *Courtesy of The Sheffield Corporation.*

and two groove diameters, on an aircraft piston by the use of electrical gage heads like those described in the previous article. A Multichek Electrigage consists of a chassis to carry the number of gage heads required, each mounted on a modified snap-gage frame, and provided with suitable gaging points or fingers which are arranged caliper-fashion to measure diameters or lengths. Minimum-

and maximum-size master gages are used when setting the gaging fingers to measure the prescribed tolerance limits. Work to be inspected is placed over a locator on a slide and moved forward between the gage points. A chart of gage-point locations on an indicator panel, and signal lights arranged behind it, show the dimensional condition of the work. A master light flashes when all dimensions are within tolerance limits, and individual signal lights indicate when and where dimensions are incorrect. There is practically no limitation on the number or type of dimensions that may be checked with this kind of gage.

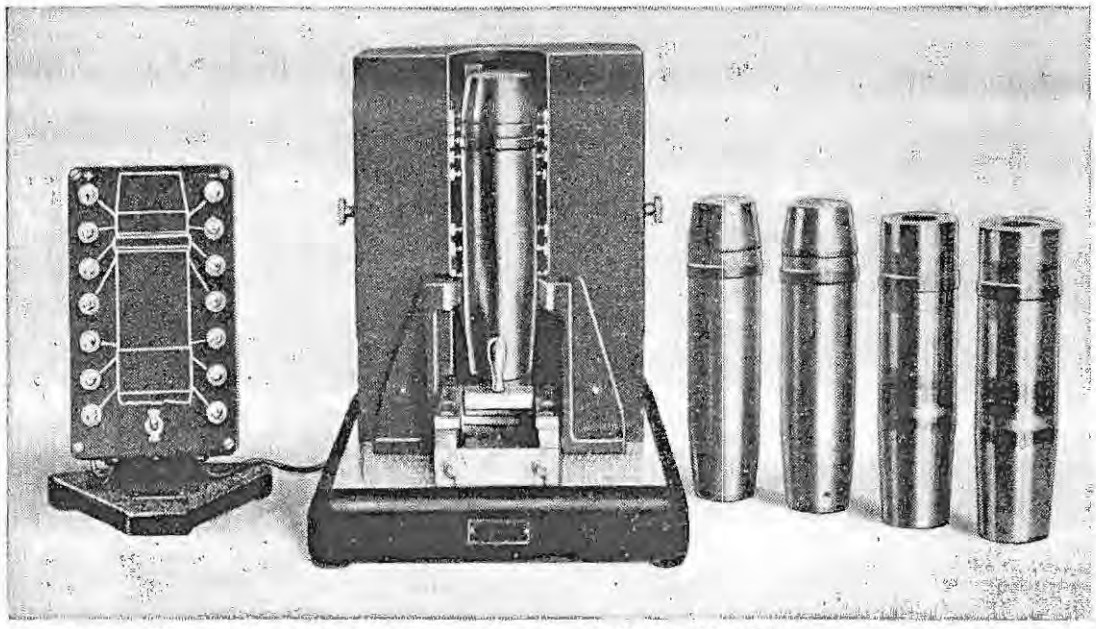


Fig. 9.18 Electrolimit shell gage. *Courtesy of Pratt & Whitney; Photo from Pratt & Whitney Division, Niles-Bement-Pond Co.*

The Pratt and Whitney Electrolimit gage, illustrated in Fig. 9.18, consists of a signal box and a gaging fixture. This gage is designed to check seven diameters of a shell simultaneously and to indicate its dimensional characteristics by means of signal lights. Red lights on the left side of the signal panel indicate oversize dimensions, green lights on the right side indicate undersize dimensions, and all lights out signify that the dimensions are within specified limits. The measuring of each dimension is performed with a caliper-like gaging section, that consists of a fixed anvil and movable spindle, which floats on a flat spring so that it may align itself automatically

with the shell. Gaging sections are set to size with two master gages that represent maximum and minimum limiting dimensions of the shell. A shell being inspected rests on a locating stud, that is part of a sliding carriage, which is moved forward against a stop to position it between the anvils and spindles of the gaging sections where the dimensions are checked. Gages of this type may be made to inspect lengths and diameters of an almost unlimited variety of workpieces.

Recall that components of the electrical comparators, described previously, are adaptable to the construction of multiple electrical gages also.

Air Gages or Comparators

An air gage, or air comparator, is an instrument that measures the size of work by comparing a standard pressure or flow of air in a compressed-air system with the pressure or flow of air during an inspection operation. Air gages have a number of advantages in inspection.

1. High amplification and accuracy can be obtained with an air gage. Ordinary amplification ranges from 625:1 to 5,000:1; but it may range as high as 60,000:1 in various makes and models of this instrument.

2. There is comparatively large clearance between the gage head and the work. This, combined with wide division spacing on the scale of the indicating instrument, makes it possible for inspectors having a minimum amount of skill to do accurate gaging.

3. Large clearance between the gage head and work has further advantages because gage wear is at a minimum, gages do not mar highly finished and soft surfaces, and thin-walled sections are not distorted or damaged by gaging pressure.

4. Air gages are adaptable to measuring and checking outside and inside diameters, taper, bellmouth, out-of-round, width and length, height and depth, and many other dimensions and conditions of work.

5. Air gages can explore deep holes more conveniently and accurately than is possible with other tools.

6. Air gages are adaptable to multiple dimension gaging.

7. Air gages may be combined with mechanical or electrical gages for multiple dimension and automatic gaging.

The essential parts of an air comparator are a supply of compressed air, an indicating instrument, a gage head, and hose or tubing to connect the foregoing components. During an inspection operation, air flows through nozzles in the gage head and escapes through a clearance space between the gage head and work. The greater the clearance, the higher will be the velocity of air in the system and the lower will be its back pressure. Therefore, two kinds of air comparators, known as flow and pressure types, are used depending on which condition is measured.

The ordinary shop supply of compressed air may be used with an air gage. Auxiliary equipment usually employed in the air-supply system are an air filter, a pressure regulator, and a pressure gage. Part or all of this equipment may be built into the air gage itself.

Gaging members consist of air plug gages, air ring gages, adjustable air snap gages, and special gaging fixtures for multiple gaging operations. Master gages are employed with gaging members to set limit pointers on the indicating gages.

CompAIRator Air Gage

A Taft-Pierce single-dial CompAIRator air gage, with an adjustable air snap gage, is illustrated in Fig. 9.19; and the CompAIRator air-gage circuit, which applies especially to this instrument, is shown in Fig. 9.20. In this circuit:

1. Compressed air enters the filter-regulator where it is cleaned and reduced to a constant pressure for use in the remainder of the circuit.

2. Next, the air enters the venturi chamber where its velocity changes and creates a pressure differential in two pressure tubes which are attached to the chamber at parts having different cross-sectional areas.

3. This pressure differential is transmitted to the indicating gage by the sensitive indicating mechanism.

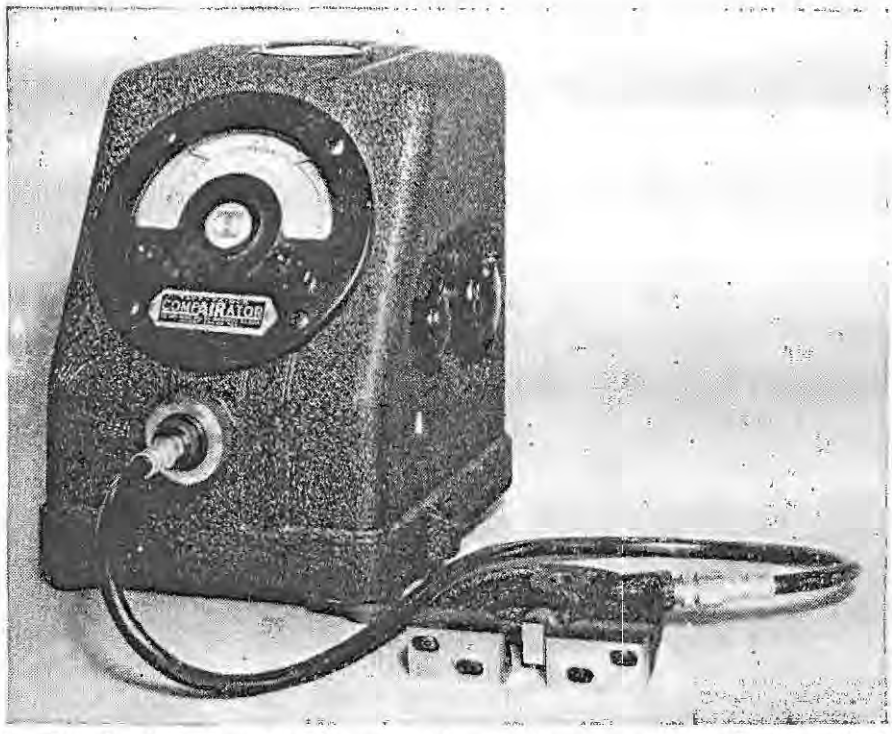


Fig. 9.19 Single-dial CompAIRator with an air snap gage. *Courtesy of The Taft-Pierce Manufacturing Company.*

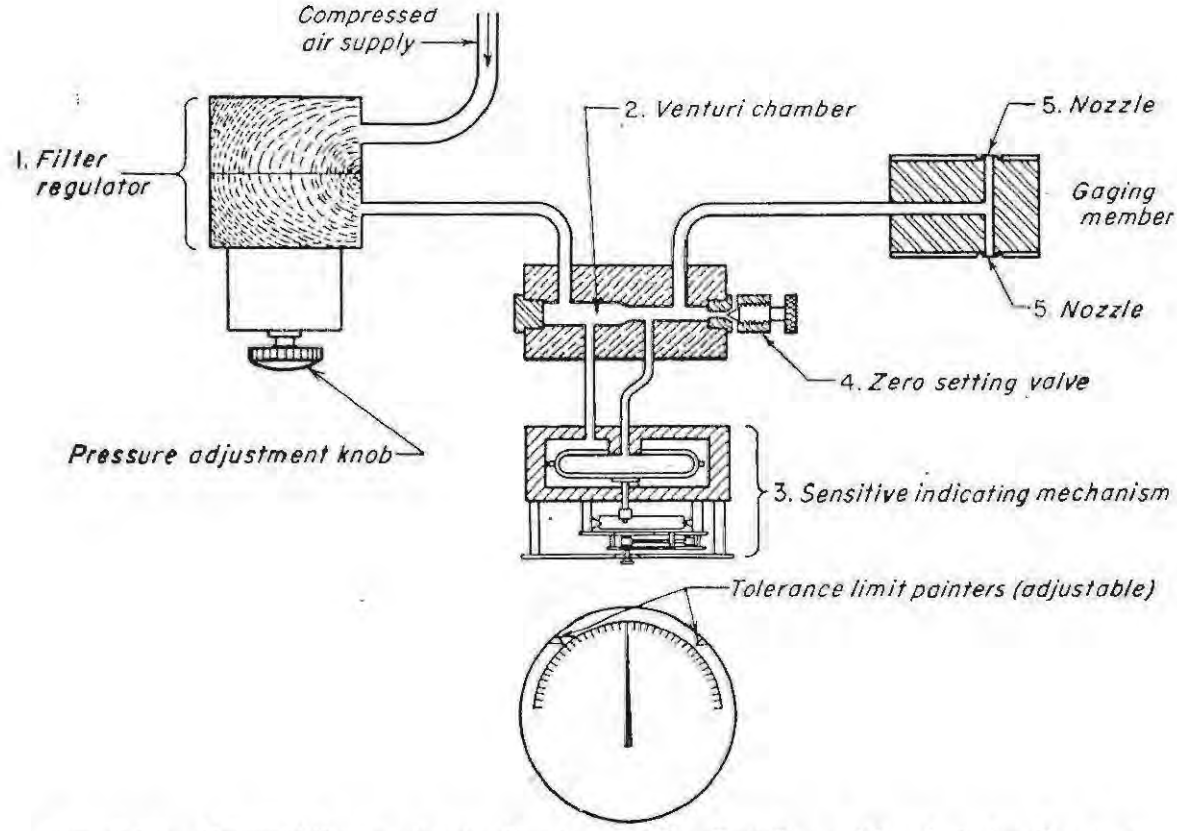


Fig. 9.20 CompAIRator circuit. *Courtesy of The Taft-Pierce Manufacturing Company.*

4. After passing through the venturi chamber, the air flows past a zero setting valve which provides a bypass to the atmosphere and a means of shifting the pointer range to any desired position on the indicator scale.

5. The air then enters the gaging member and is discharged through the nozzles. When work is placed over the nozzles, the

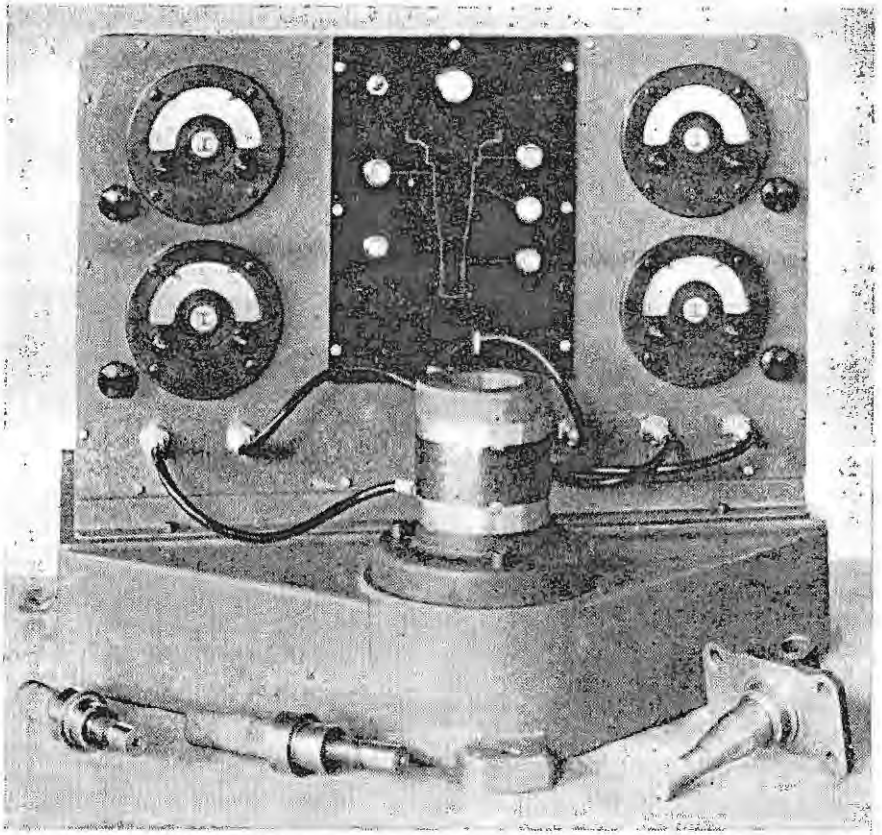


Fig. 9.21 Special four-dial CompAIRator. *Courtesy of The Taft-Pierce Company.*

flow of air is restricted and its velocity is reduced. This changes the pressure differential in the sensitive indicating mechanism and causes a change in the dial reading.[1]

A special four-dial CompAIRator with a gaging fixture and signal lights for inspecting five diameters of an automobile axle is illustrated in Fig. 9.21. Shown, with one of the axles, are the minimum- and maximum-size master gages for setting the tolerance pointers to indicate the tolerance zones.

[1] This description of the CompAIRator circuit is furnished by The Taft-Pierce Manufacturing Company and is reproduced with its permission.

Precisionaires

A Sheffield airflow column-type Precisionaire with an air spindle for checking internal dimensions is shown in Fig. 9.22. This is a flow-type air gage. Compressed air enters the gage through a pressure-regulating valve and passes upward through a transparent tube and out through an orifice in the gaging spindle. The transparent

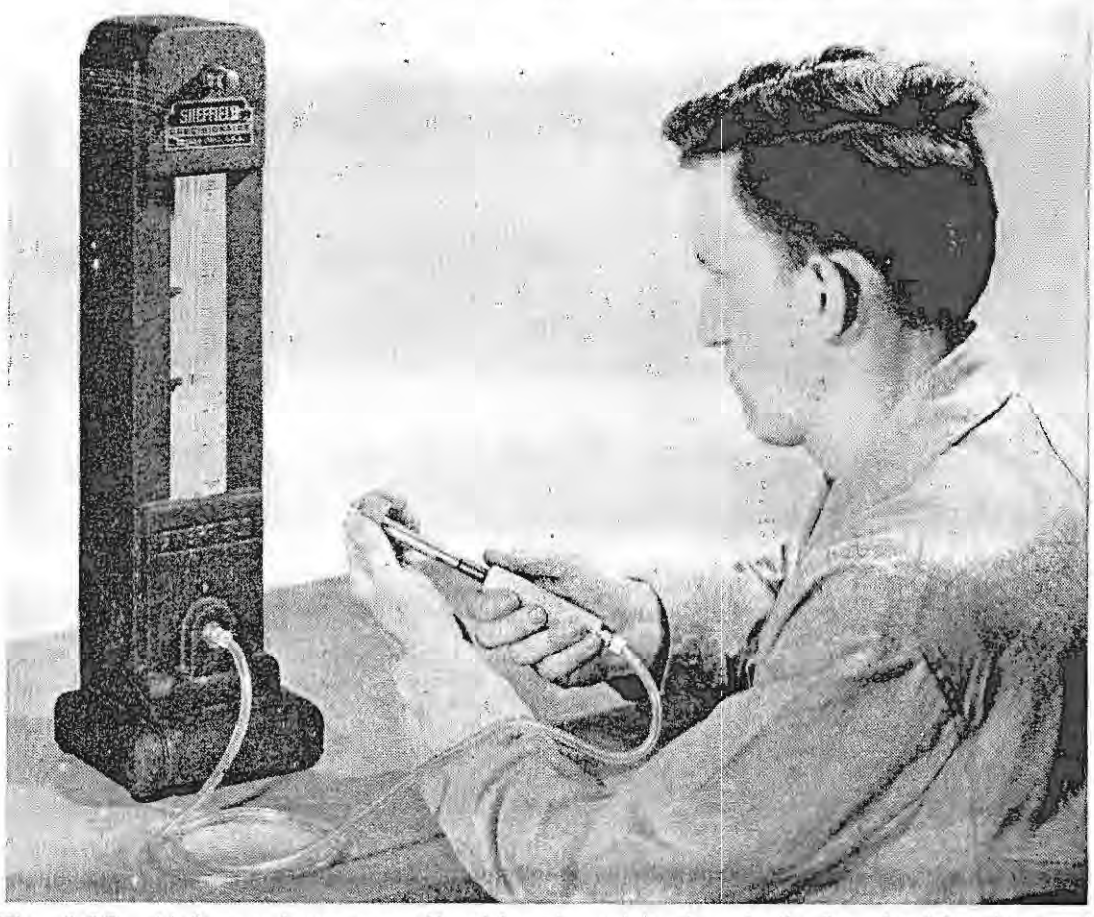


Fig. 9.22 Airflow column-type Precisionaire with air spindle for checking internal dimensions. *Courtesy of The Sheffield Corporation.*

tube has a tapered bore with the large diameter at the top, and it constitutes the indicator on the instrument. A float in the indicator tube, opposite the lower tolerance pointer in the illustration, is free to rise and fall in response to changes in the velocity of air passing through the tube and around the float. The greater the velocity of the air, the higher the float will rise in the tube. When work is gaged, the flow of air is restricted, its velocity is reduced, and the float either drops from the top of the tube to a level where its

position can be read on a scale beside the tube or it drops in its relationship to the tolerance pointers. Columns and scales of these instruments are linear throughout their lengths, and the scales are reversible to change the zero location for external and internal measurements. The tolerance pointers beside the tube are adjustable.

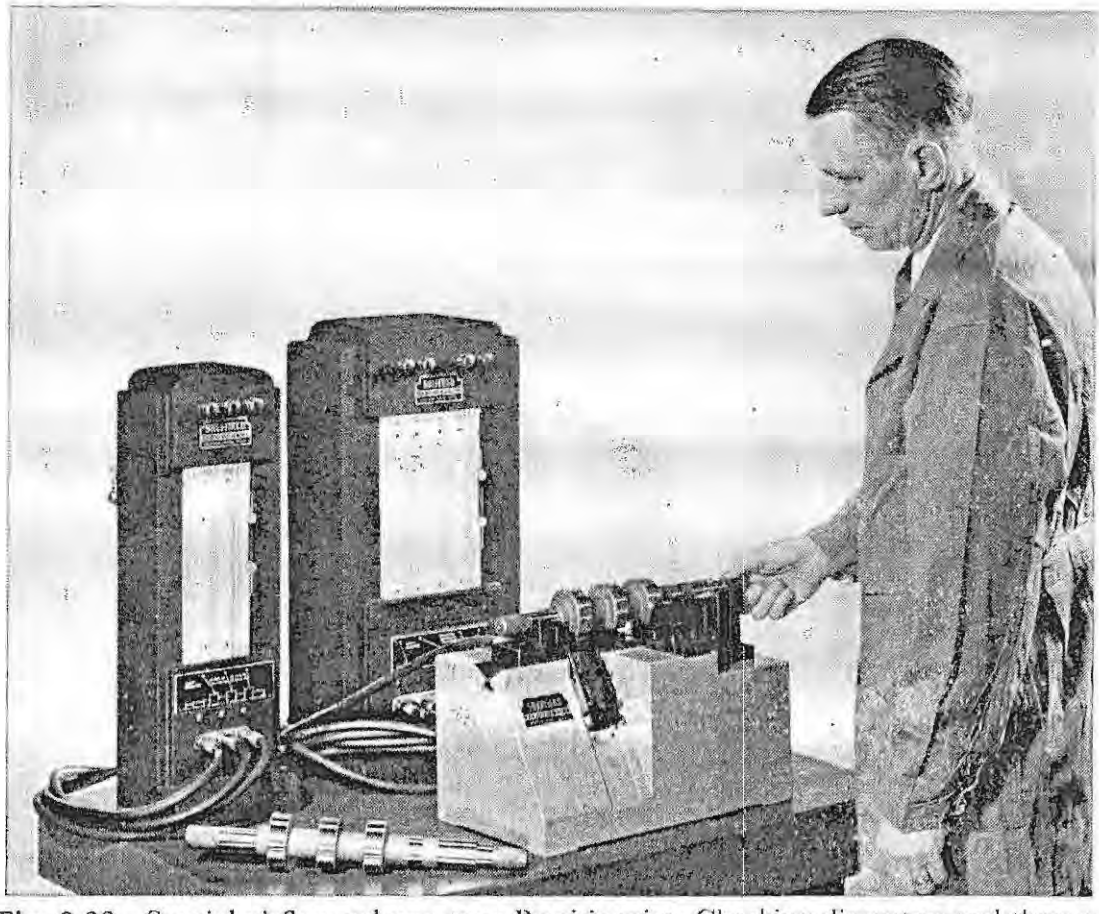


Fig. 9.23 Special airflow column-type Precisionaire. Checking diameters and throws of refrigerator crank shafts. *Courtesy of The Sheffield Corporation.*

A special airflow column-type Precisionaire for multiple inspection of the diameters and throws of a refrigerator crankshaft is shown in Fig. 9.23. This instrument is adjustable for inspecting four different designs of crankshaft.

The Sheffield dial-type Precisionaire is a pressure-type instrument. The gaging member may be mounted directly on the gage for checking work presented to it, or it may be connected to the gage with a hose for use in remote gaging.

Metricator and Dimensionair

The Federal Metricator or Lo-pressure Air Gage, shown in Fig. 9.24, operates on an air pressure of only 1 or 2 psi. It is recommended as being especially suited for gaging porous, soft, and flexible materials. The indicating tube of this instrument is, essentially,

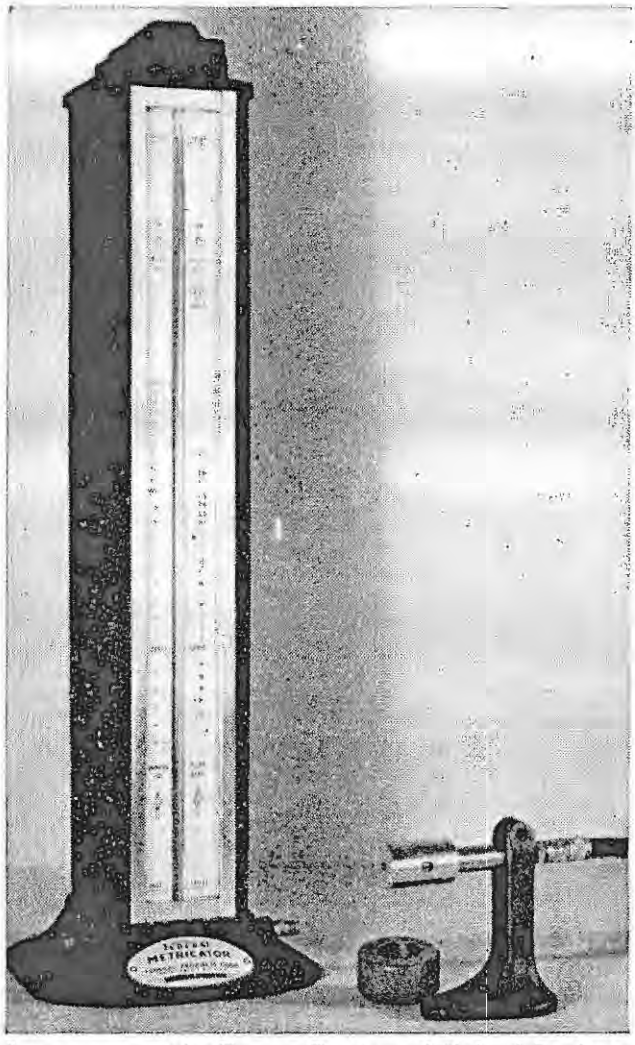


Fig. 9.24 Lo-pressure Air Gage. *Courtesy of Federal Products Corporation.*

one side of an open-tube manometer. When work is inspected, back pressure forces a liquid in the indicating tube downward from its static level to a lower level where its height may be measured on a linear scale beside the tube as a dimension of the workpiece.

The Federal Dimensionair is a high-pressure dial-type gage which operates on any pressure of reasonable fluctuation between 40 and 100 psi.

QUESTIONS

1. What is a dial indicator?
2. Name and describe five types of dial gages.
3. List advantages possessed by the following types of gages or comparators: (*a*) mechanical gage, (*b*) Visual Gage, (*c*) electrical gage, (*d*) air gage.

10

OPTICAL MEASURING INSTRUMENTS

Optical measuring instruments to be described in this chapter are those that produce magnified images of work which permits visual examination of details too small to be seen with the unaided eye. These instruments range from simple magnifiers to microscopes and projectors that are arranged to make precision linear and angular measurements with micrometers, gage blocks, and protractors, or to compare the contours of images with charts that are drawn to the same scale as the magnifying power of the instrument.

Magnifiers

A wide-field magnifier, mounted on an adjustable stand that leaves the inspector's hands free to manipulate work, is shown in Fig. 10.1. This instrument covers a field of 1½ in. at a 3 power or 3× magnification.

An illuminated magnifier, illustrated in Fig. 10.2, is so constructed that light is directed on work from a small fluorescent lamp at the rear to give good visibility without glare in the inspector's eyes. The 5-in. diameter lens has a 2× magnifying power and a 13-in. focal length. An auxiliary lens is available to provide double magnification. The adjustable stand is a convenience for holding the magnifier in position during inspection operations.

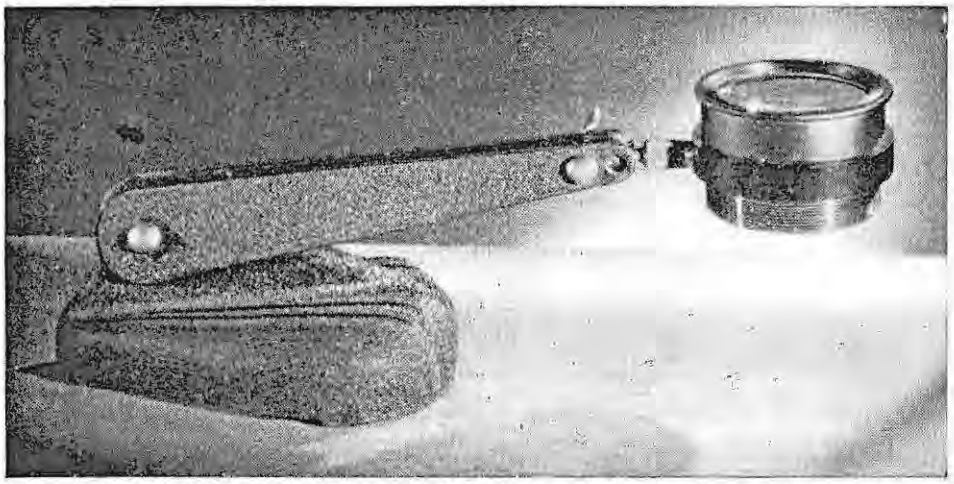


Fig. 10.1 Wide-field magnifier on adjustable stand. *Courtesy of Bausch & Lomb.*

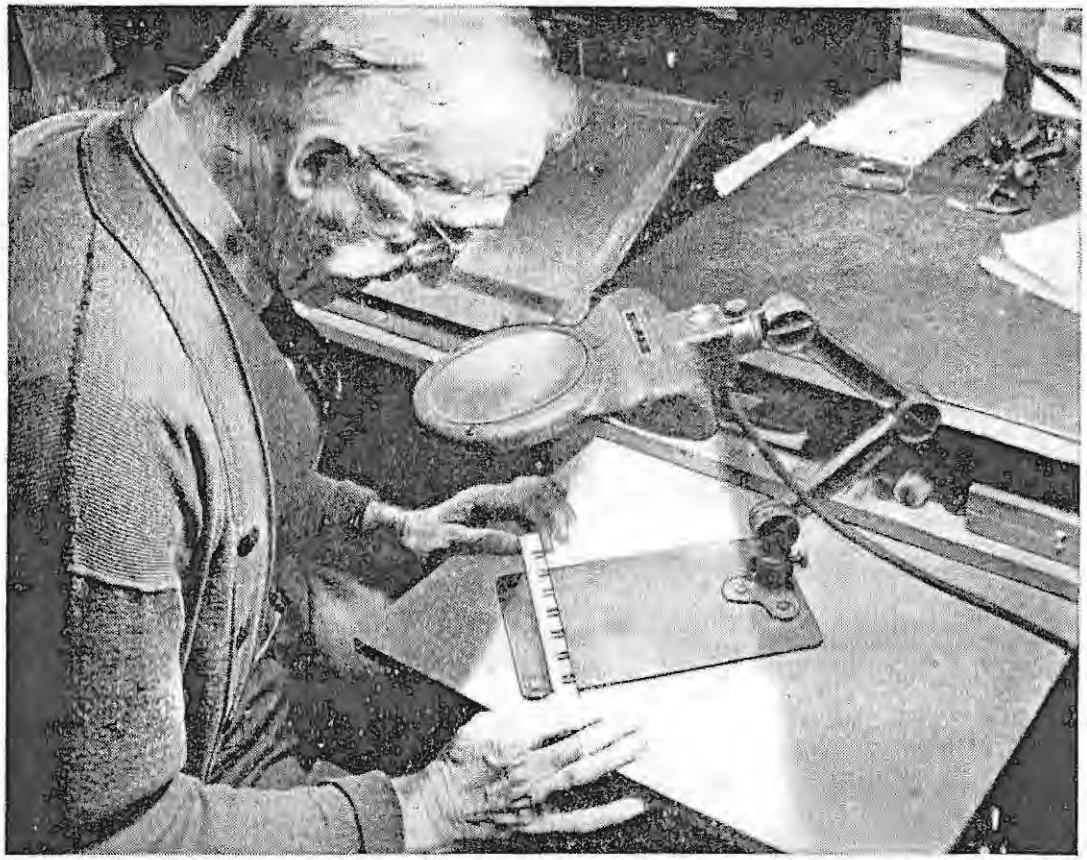


Fig. 10.2 Illuminated magnifier on an adjustable stand. *Courtesy of Stanley Rule and Level Co.*

Shop Microscope

The shop microscope, shown in Fig. 10.3, has a self-contained illuminator, an engraved scale mounted in the body of the microscope tube that reads directly to thousandths of an inch, and a 40× magnifying power. The battery-operated illuminator makes it pos-

sible to use this instrument in dark areas. This tool is useful for examining cracks, flaws, and blow holes in the work, and for measuring the diameters of small holes, impressions of Brinell hardness tests, and similar applications. An eyepiece view of a crack seen through the Bausch and Lomb shop microscope is shown in Fig. 10.4. In use, the microscope is placed on the surface of the part to be inspected, and the illuminator button is pressed. This illuminates the specimen with a grazing light which, because of the deep shadows cast, is effective for the detection of surface characteristics.

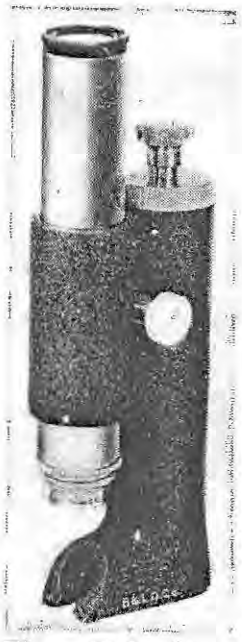


Fig. 10.3 Shop microscope. *Courtesy of Bausch & Lomb.*

Pocket Comparator

The pocket comparator, shown at *A* in Fig. 10.5, is a precision measuring instrument for inspecting small parts. Measuring is accomplished by a combination of a magnifying lens and a reetile, engraved in the pattern shown at *B* in the same figure, to permit accurate measurements of lengths, widths, diameters, radii

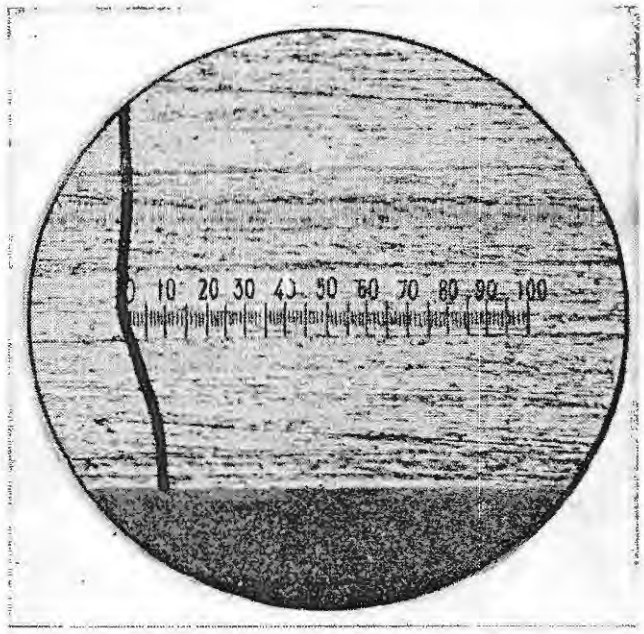


Fig. 10.4 Eyepiece view of crack seen through Bausch & Lomb shop microscope. *Courtesy of Bausch & Lomb.*

and angles. Linear dimensions from 0.001 to 0.500 in., diameters and radii from 0.002 to 3/8 in., and angular dimensions from 0 to 90 deg by 5-deg intervals may be measured. The instrument is applied by resting the rectile directly on the work in such a manner that the greatest possible amount of illumination will enter through the transparent plastic spacer at the bottom. Then the instrument is moved until the proper mark on the rectile is over that part of the

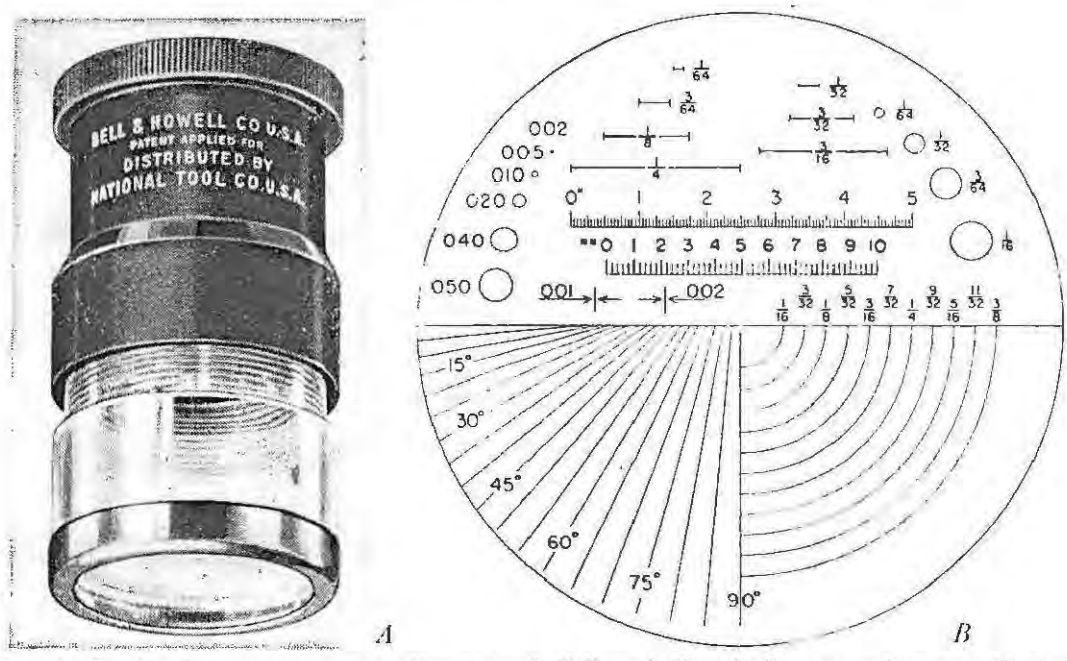


Fig. 10.5 Pocket comparator. *Courtesy of Bell and Howell Co., manufacturer; National Tool Co., distributor.*

surface which is to be measured. If the rectile or work is obscure, focus the comparator by adjusting the spacer in the main body of the instrument until the greatest clarity is obtained. This is a screw adjustment.

Toolmakers' Microscope

The toolmakers' microscope is a precision instrument that is designed for use by machinists and toolmakers to inspect work by measuring the coordinates of points. It shows objects and movements in their natural aspect and direction instead of reversed as in the ordinary laboratory microscope.

The toolmakers' microscope that is illustrated in Fig. 10.6 con-

sists of a base, a cylindrical steel column that rises vertically from the rear of the base, a microscope unit mounted on the column, and a compound cross-slide stage, or table, mounted on top of the base.

The microscope unit may be arranged on the column at any convenient working distance up to 6 in. above the microscope stage.

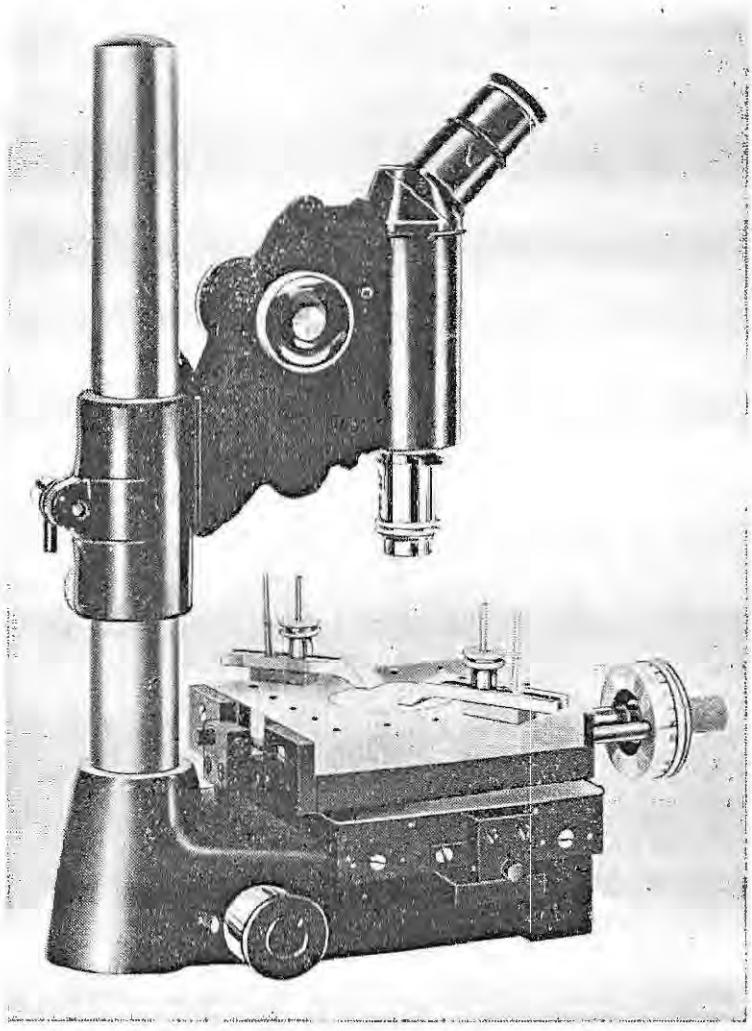


Fig. 10.6 Toolmakers' microscope. *Courtesy of Bausch & Lomb.*

Fine adjustment of the microscope tube for focusing the instrument is obtained with a rack-and-pinion motion. The microscope eyepiece has a cross-line disk in its focal plane with lines intersecting at 30, 60, 90, 120, and 150 deg for measuring angles having these magnitudes, and the eyepiece is provided with an adjustable eye lens for focusing sharply on the cross lines. Regular lens equipment

furnished with this instrument gives a magnifying power of 42×; however, other objectives and eyepieces may be obtained to give different magnifications.

The compound cross-slide stage of the microscope has a movement of 1 in. in two horizontal directions at 90 deg to each other. Movement of the stage is controlled by two micrometer screws that are fitted with large-diameter drums which are graduated to give readings in ten-thousandths of an inch. If greater accuracy is required, precision gage blocks may be used to measure movements of the cross slides. A quartz cover glass is set into the upper surface of the cross-slide stage to serve as an object carrier and to permit light from underneath to travel upward through the cross-slide stage for examination of transparent objects.

Work to be inspected is laid on the cross-slide stage. Then the microscope is focused on the part, and the point of origin for measurements is brought under the cross lines seen through the eyepiece. Movement of the stage with the micrometer screws to bring a second point under the cross lines gives measurements that locate the second point relative to the first. Measurements to a series of points, made in this manner, may be used to check a contour.

Clamps, center attachment, other accessories for holding work, and a surface illuminator and a protractor eyepiece are available as regular or extra equipment for use with this instrument.

Toolmaker Microscope

The toolmaker microscope, shown in Fig. 10.7, is a larger instrument than that described in the previous section, and it has features designed especially for screw-thread inspection. The principal parts of this tool are a base, table, cradle and centers, upright, and microscope unit.

The microscope measures rectangular coordinates through the use of a compound cross-slide table. Each cross slide has a movement of 2 in. that is controlled by a micrometer screw, and the longitudinal cross slide has an additional movement of 2 in. that can be measured with precision gage blocks through the use of a

subslide. The micrometer drums are graduated to read directly in ten-thousandths of an inch.

This microscope may be obtained with a 6½ by 8 in. rectangular table or with a rotary stage, as shown in Fig. 10.8. The protractor

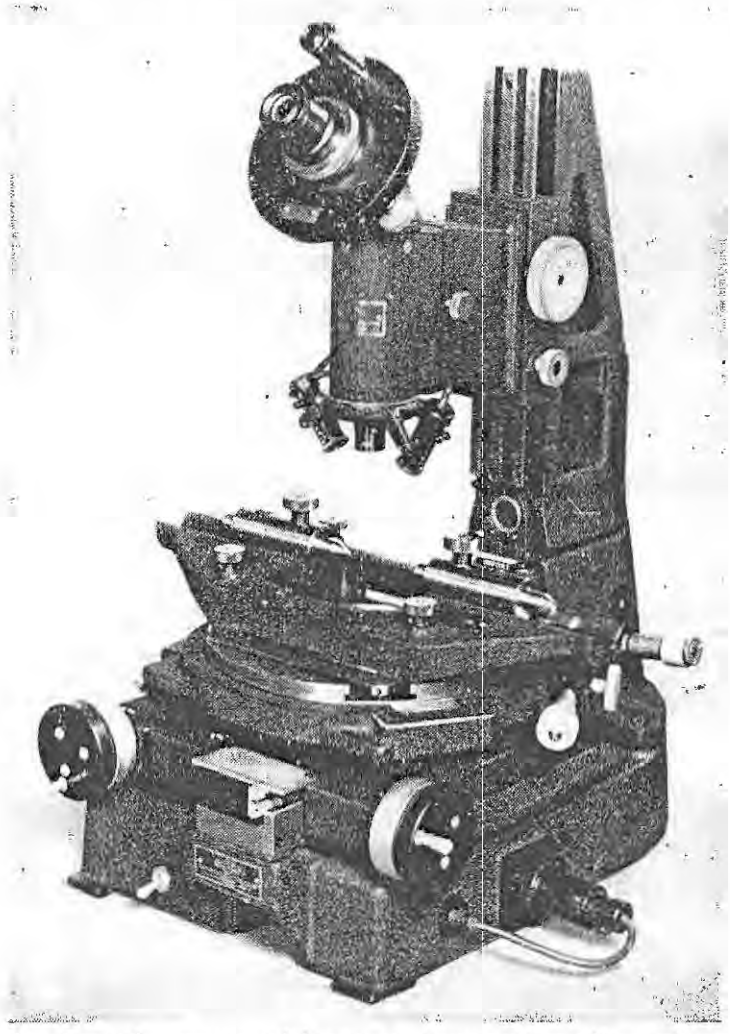


Fig. 10.7 Toolmaker microscope with rotary stage and cradle and centers. *Courtesy of Gaertner Scientific Corporation.*

on the rotary stage is graduated in degrees and half degrees, and a vernier beside it permits readings in minutes. The cradle and centers, shown in Fig. 10.7, are furnished as regular equipment with this instrument.

The microscope unit, mounted on an upright that rises from the rear of the base, may be adjusted vertically up to a distance of 8 in. above the table with a rack-and-pinion mechanism. The cross lines,

seen through the main eyepiece of the microscope, are on separate rectiles, one of which is adjustable so that it may be set at any angle relative to the other. An optical protractor on the microscope head is graduated in degrees, and a vernier permits readings in minutes. The magnifying power of the microscope is 30×.

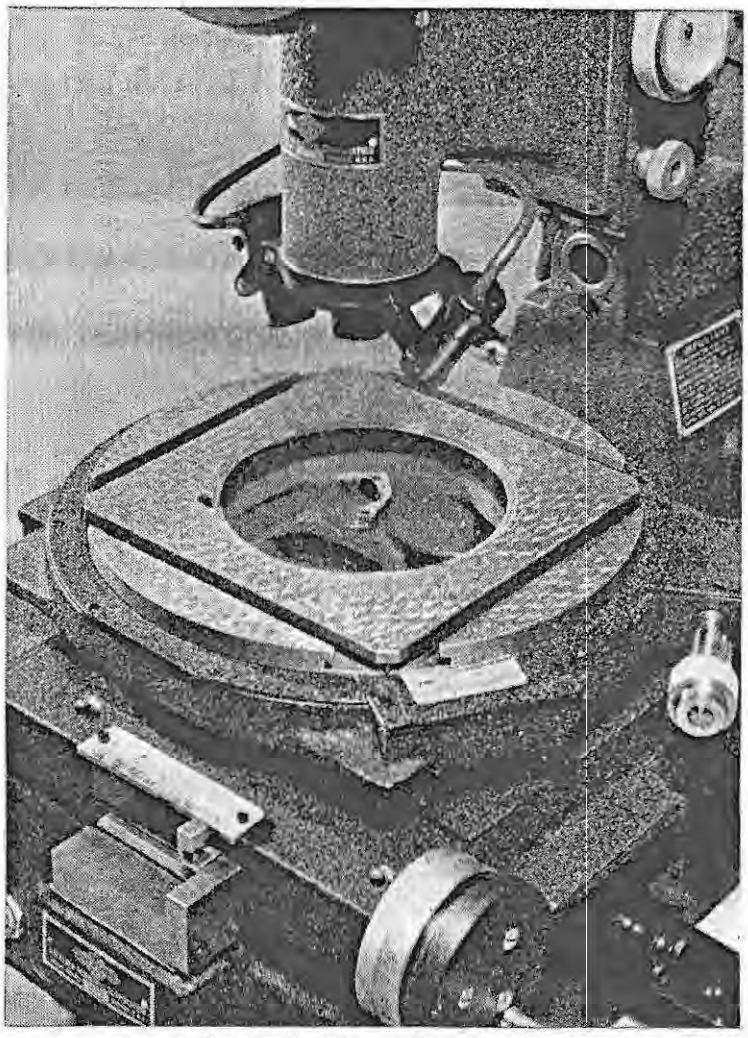


Fig. 10.8 Rotary stage of the toolmaker microscope. *Courtesy of Gaertner Scientific Corporation.*

This instrument has two special provisions for inspecting screw threads. First, the upright may be tilted to the helix angle of a thread so that a clear view of both sides of the thread may be obtained at the same time. Second, an interchangeable ocular head is available that contains a glass slide with American National Standard screw-thread profiles engraved on it. These profiles, for

6 to 80 threads per inch, may be used to check threads by direct comparison instead of measuring their elements.

Projection Comparator

A projection comparator is an instrument which illuminates an object being inspected so that a shadow of its contour is cast on a projection lens. The lens magnifies the shadow and projects it onto a mirror which reflects the image onto a screen where it may be inspected visually.

The projection method of inspection has several advantages over mechanical methods on work of a suitable nature.

1. It is an easy matter to train beginners to use this method of inspection.

2. Several persons can view an object at one time and all will see the same thing.

3. Pressure and feel, as elements affecting judgment, are eliminated.

4. Often all parts of an object can be examined at one time. It is not necessary to use multiple gages to inspect a part.

5. Many parts can be set up and measured without the use of holding fixtures. Standard fixtures may be used to hold many other parts.

6. This type of gage is not subject to progressive deterioration from wear.

7. The advantages that have been named combine to produce a faster and more accurate method of gaging work of a suitable character than is possible with other methods. Figure 10.9 shows a number of precision parts that are typical of those which may be inspected rapidly, accurately, and economically by the projection method.

Although projection comparators differ in details of construction and refinement, they have certain features in common. These are a source of light, a system of condensing lenses that concentrate light from the source on the object being inspected, so that it will cast a shadow on a projection lens, a projection lens to magnify the

image of the shadow and throw it onto a mirror, a first-surface mirror or mirrors to reflect the image onto a screen, a screen to receive the magnified image, and a stage or table on which the work is set up during inspection. Lenses for general work on these instruments give magnifications of 10×, 20×, 31¼×, 50×, 62½×, and 100×. Other magnifications are available on special order.

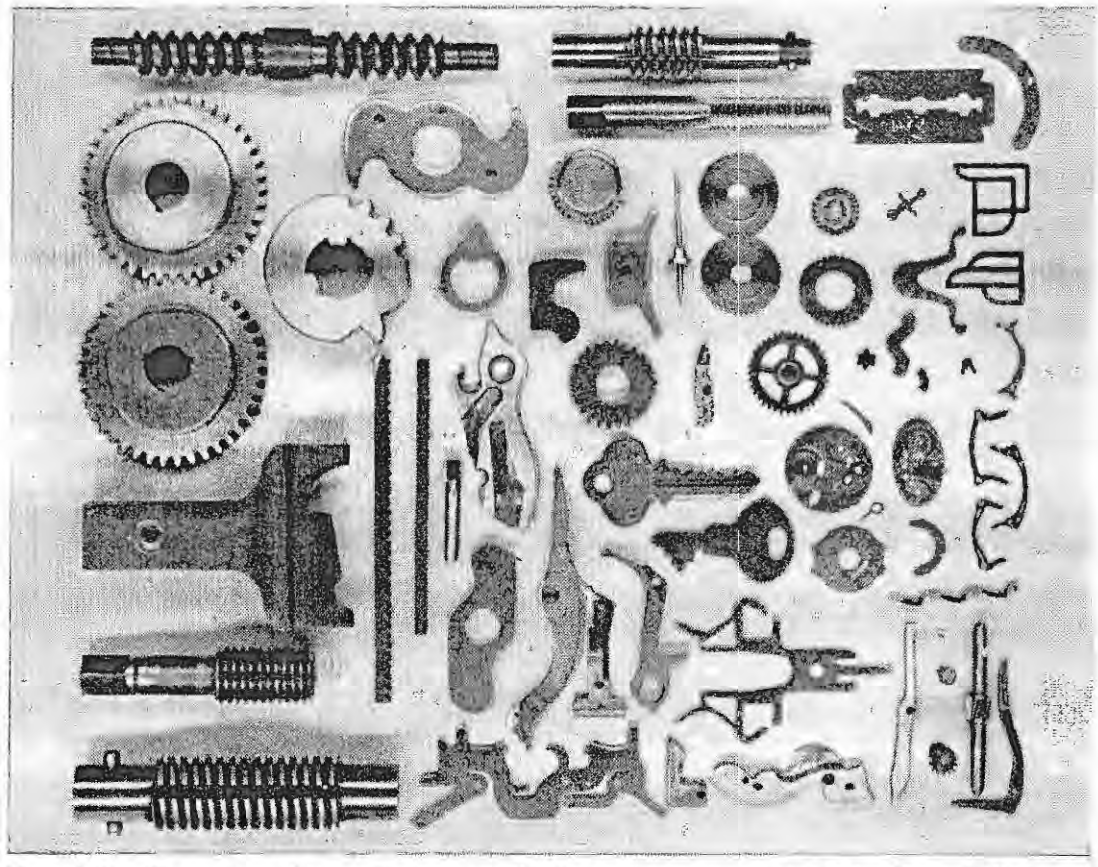


Fig. 10.9 Examples of irregular parts which can be measured on the Bausch & Lomb contour measuring projector. *Courtesy of Bausch & Lomb.*

A projection comparator may be used to check the profile of work by measuring the coordinates of points, or by comparing it with a master outline.

1. To measure the coordinates of points, the work is set up on the cross-slide stage or table of the comparator, and its shadow is aligned with cross lines on the screen to locate the point of origin for measurements. Then, coordinate movements of the stage or table to align other points with the cross lines are

measured with micrometers that are a part of the construction, or with gage blocks which are inserted between gaging surfaces.

2. To compare a contour with a master outline, the work is set up on the stage or table and moved to align its shadow with the master outline which is mounted on the screen.

Wilder Model B Micro Projector

The Wilder Model B Micro Projector, shown in Fig. 10.10, is a bench-type instrument that employs the optical system shown in

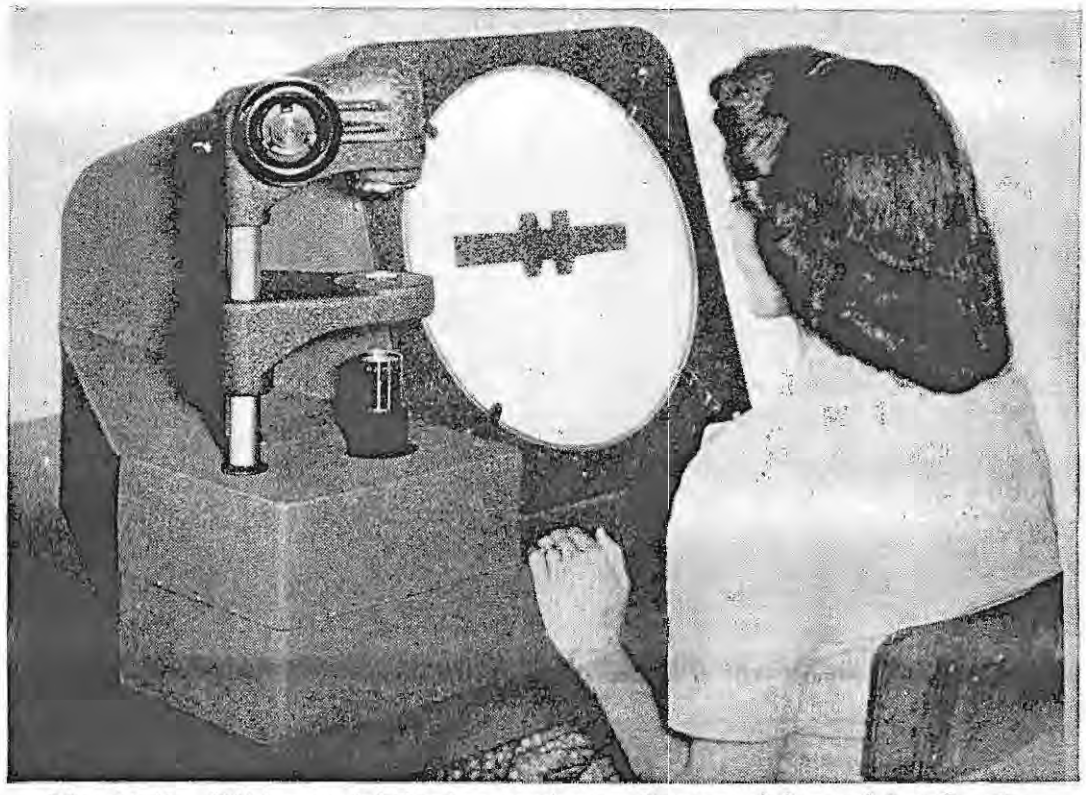


Fig. 10.10 Wilder model B micro projector. *Courtesy of George Scherr Co., Inc.*

Fig. 10.11. The light source is mounted in a lamp house that also encloses gears for raising the table into proper focus. A condensing lens concentrates parallel beams of light on any object that is laid on the horizontal worktable. A shadow of the object is cast on the projection lens, and the lens magnifies and projects the image onto the understage mirror. The understage mirror reflects the image to the rear mirror which, in turn, reflects it onto the screen.

The screen is 14½ in. in diameter. A ground-glass screen with 90- and 60-deg cross lines is recommended for measurements with the compound cross-slide stage, and a clear glass screen for comparison against drawings.

The compound micrometer cross slide is shown in Fig. 10.12. This replaces the ground glass stage for actual measurement of work.

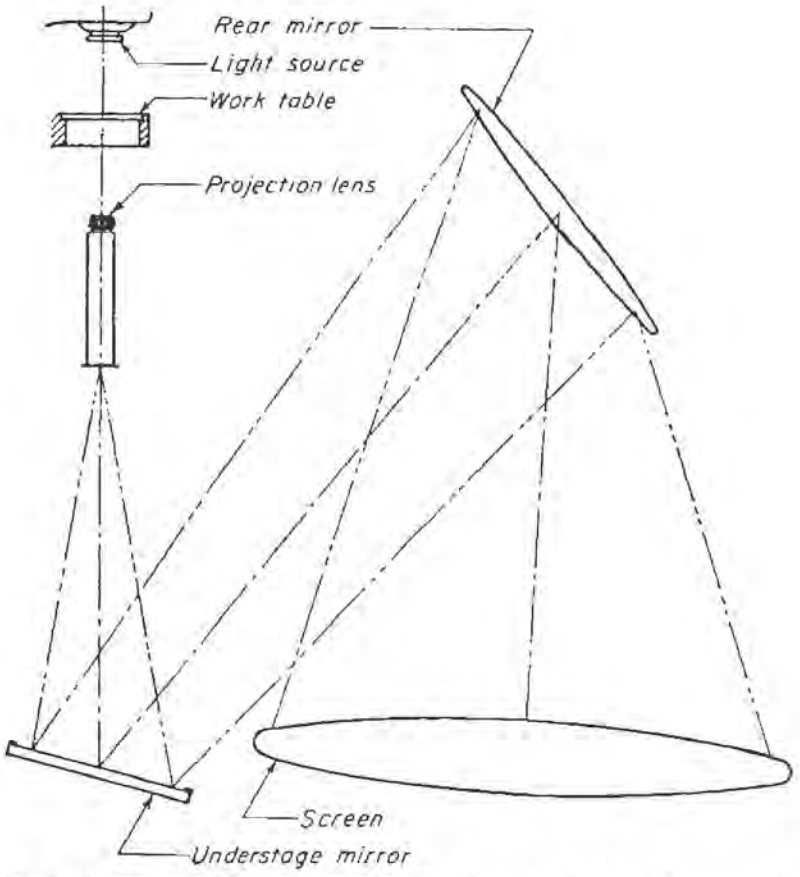


Fig. 10.11 Optical system of Wilder model B micro projector. *Courtesy of George Scherr Co., Inc.*

The standard model has a 1- by 1-in. capacity reading in thousandths of an inch, and a special model has a capacity of 1 by 2 in., reading in five ten-thousandths of an inch.

A center support for holding work on centers is available as extra equipment. Its usefulness for measuring threads is increased by provision for tilting work either side of center to the helix angle of the thread.

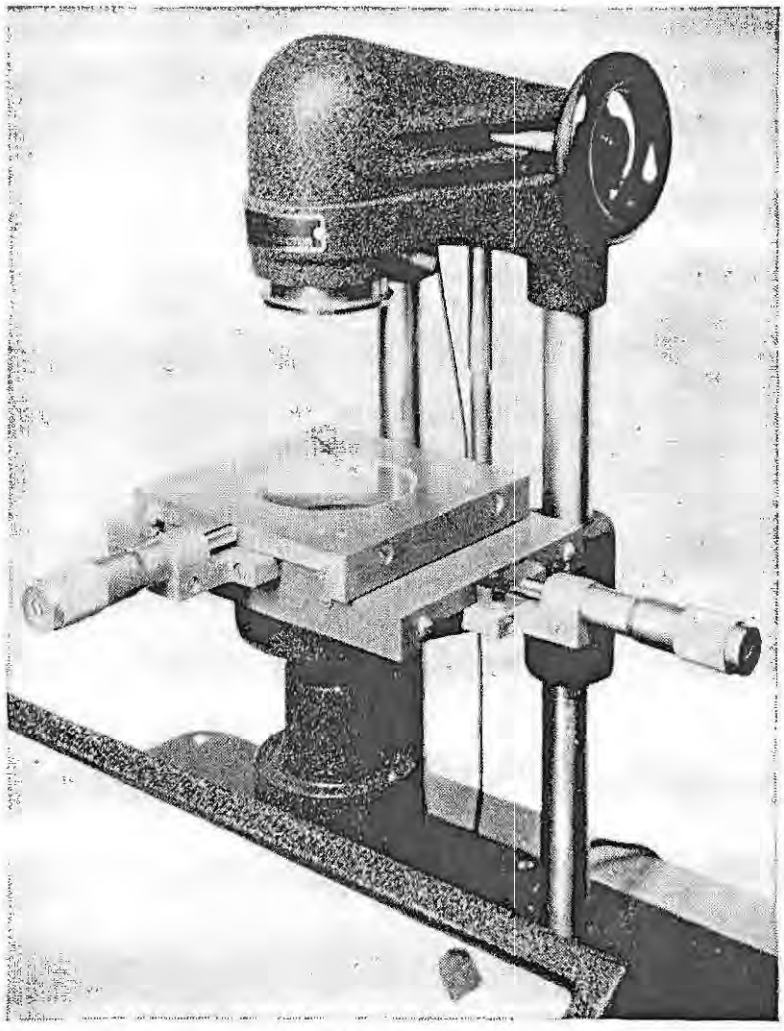


Fig. 10.12 Micrometer cross slide for Wilder micro projector. *Courtesy of George Scherr Co., Inc.*

Jones and Lamson Optical Comparator

The Jones and Lamson Pedestal Optical Comparator and Measuring Machine is shown in Fig. 10.13. The optical system of this comparator directs a horizontal beam of light across work that is held on the table with staging fixtures. The projection lens, which is mounted just under the screen, projects an enlarged image of the object onto an optically flat mirror at the back of the hood, and the mirror reflects the image onto the 14-in. diameter translucent receiving screen at the front of the hood.

The circular screen is held in the graduated ring of an angle-measuring attachment. The ring has one-half degree graduations, and a vernier segment beside it permits readings to one minute

which are accurate to plus or minus two minutes of arc. Two lines at right angles meet in the center of the screen, and a 30- to 60-deg line is located in one of the quadrants. Spring hold-down clips on the graduated chart ring are provided for holding charts on the screen. An adapter can be mounted in place of the standard chart ring and screen to hold 8- by 10-in. translucent charts and photographic plate holders.

Three types of tables are available for this projector: an 18-in. table with a 4-in. lateral travel, a 30-in. table with a 4-in. travel, and a 30-in. table with an 8-in. travel. Lateral movements of the table may be made with micrometers or gage blocks. The standard micrometer is graduated to read in five ten-thousandths of an inch. A micrometer graduated to read in one ten-thousandth of an inch can be supplied if desired.

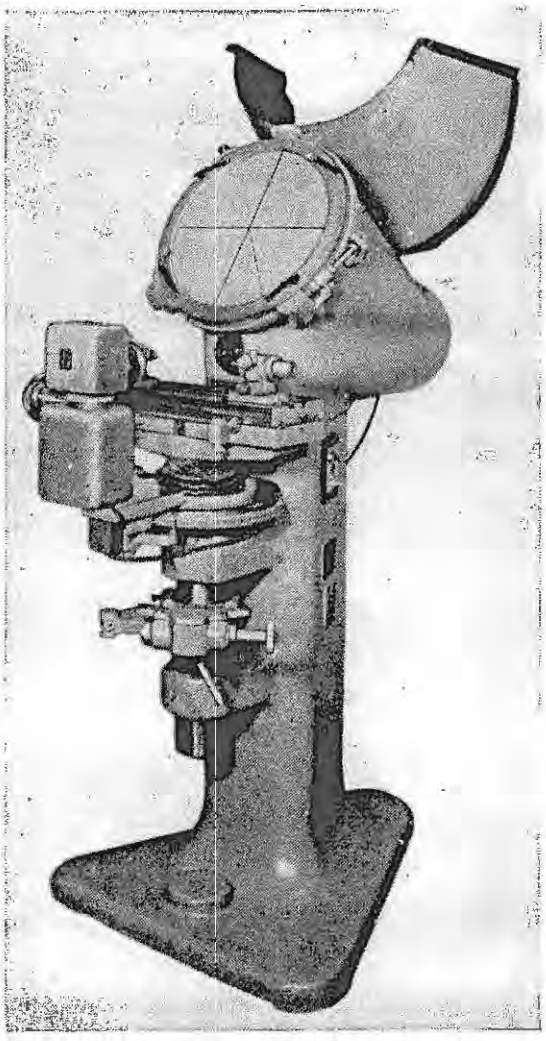


Fig. 10.13 Pedestal optical comparator and measuring machine, model PC-14. *Courtesy of Jones & Lamson Machine Company.*

The table is mounted on top of a table column that is held in brackets on the front of the pedestal. A graduated hand wheel for elevating the table permits vertical movements over a range of 4 in. by ten-thousandths of an inch. A table angle attachment, consisting of a sector graduated in one-half degree divisions and a one-minute vernier, is used to position the helix angle of threads parallel to the path of light.

Frosted or clear glass screens, or plastic charts with standard or special designs, are available for use on this instrument.

Jones and Lamson makes several models of both pedestal- and bench-type optical comparators.

Bausch and Lomb Contour Measuring Projector

The Bausch and Lomb Contour Measuring Projector, shown in Fig. 10.14, is a floor-type instrument that employs the illuminating and projection systems shown in Fig. 10.15.

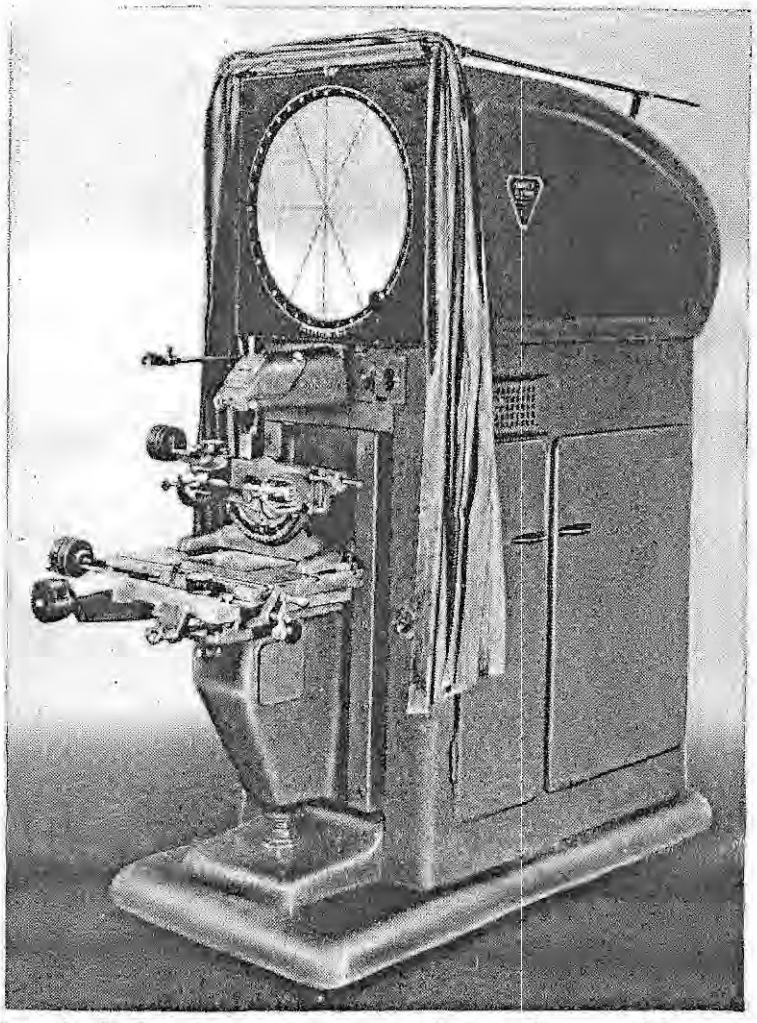


Fig. 10.14 Bausch & Lomb contour measuring projector with protractor screen, screw-thread accessory, cross-slide work table, longitudinal and transverse measuring attachments. *Courtesy of Bausch & Lomb.*

The illuminating system consists of a light source, achromatic condensers, and an illuminating mirror. The light source is a tungsten arc light. Light from the lamp passes through a pair of achromatic condensers in which each lens assembly is made of two kinds of glass to avoid the formation of color fringes. Next in the path of

light is an auxiliary condenser, not shown, that increases the amount of illumination on the screen when projection lenses of 31¼× or higher are being used. This condenser is swung out of the light path when lower powered lenses are employed. These condensers transmit the light in a parallel beam to the illuminating mirror, and the

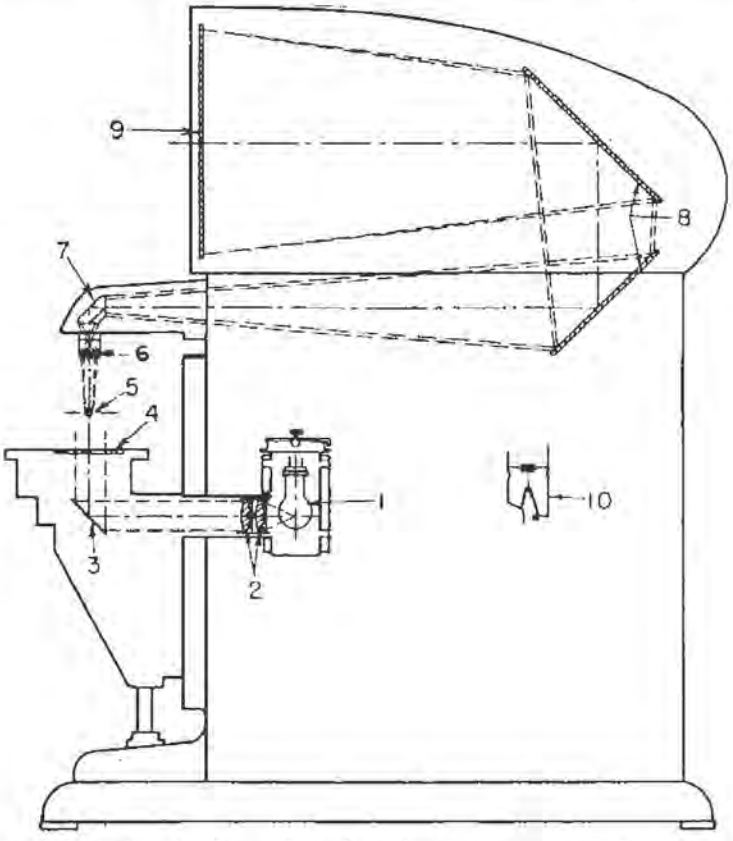


Fig. 10.15 Path of light in the Bausch & Lomb contour measuring projector. (1) light source, (2) achromatic condensers, (3) illuminating mirror, (4) glass stage plate, (5) object, (6) projection lens, (7) roof prism, (8) first-surface mirrors, (9) translucent screen, (10) diagram of filament and glower arrangement in tungsten arc light source. *Courtesy of Bausch & Lomb.*

mirror reflects the light upward through the glass stage plate, past the object being inspected.

The projection system consists of the projection lens, the roof prism, two first-surface mirrors, and the translucent screen. Light from the illumination system passes the object, and an image of the object is thrown on the projection lens. The projection lens magnifies the image and directs it to the roof prism. The roof prism directs the image horizontally toward the back of the projector to two first-surface mirrors that change the direction of the beam of

light and direct the image to the translucent screen on which the image is received and inspected. The image on the screen is erect through action of the roof prism and mirrors; that is, the image on the screen is in the same position as the object seen on the stage plate, and movement of the object on the stage plate will cause a corresponding movement of the image on the screen.

Several types of interchangeable screens are available for use on this projector.

1. A plain ground-glass screen, 18 by 18 in., can be used to observe the image of an object. If desired, a master part can be set up on the table of the instrument and its image projected to the screen. Then an outline of the image can be traced on the screen with a sharp, hard pencil. The chart, prepared in this way, can be used for comparison inspection of like parts. In preparing the chart, the outline can be followed to 0.02 in. easily, and to 0.01 in., with care. At 50× magnification, with a departure of 0.02 in. from the image outline, the tracing will be accurate to 0.02 in. ÷ 50 = 0.0004 in. of the part projected. After a chart has served its purpose, the tracing may be washed off of the screen with soap and water.

2. A protractor screen, 18 in. in diameter, is used to measure angles on the image. It consists of a disk of ground glass that is mounted in a protractor ring which is graduated in half-degree divisions. Divisions on the ring are marked 0–180 deg–0; and, in addition, 0–360 deg counterclockwise. A double vernier permits reading the protractor to 1 minute of arc. The ground glass of the screen is marked with two pair of reference lines that converge at the center. The lines of one pair are at 90 deg to each other; and the lines of the other pair, symmetrical with respect to the vertical line of the 90-deg pair, are at 60 deg to each other.

3. An 8- by 10-in. photographic-plate holder may be placed in a suitable frame so that a photograph of a magnified image may be made for use as a standard outline.

Two worktables are available for use with the projector. One is a compound cross-slide type that has a longitudinal travel of 6 in. and a transverse travel of 4 in. This table may be furnished with

micrometer accessories, the micrometers of which have a range of 1 in. and are graduated to read by ten-thousandths of an inch. A dial gage is used with each accessory as a pressure indicator. Gage blocks are used between the ends of the micrometer spindles, and the dial-gage push rods to measure dimensions greater than 1 in.

A piece of plate glass is recessed into the top of each table, and most objects to be measured may be placed on it without need for other holding means. Standard accessories, such as centers, V blocks, screw-thread holders, and special fixtures are attached in T slots and V grooves in the upper surfaces of the tables. The screw-thread accessory, shown in Fig. 10.14, is a special support for standard centers which is so constructed that it may be rotated through the helix angle of a thread so that the thread groove is parallel to the travel of light.

The worktables are mounted on top of a knee casting at the lower front of the projector. An elevating screw, through the center of the knee casting, is connected by a gear train to a reversible motor inside the cabinet. This motor, which is controlled by two push buttons located to the right and below the screen, is used to elevate the table for focusing the shadow image sharply on the screen. Automatic safety switches prevent jamming of the mechanism.

QUESTIONS

1. The symbol 3×, for example, is used in describing an optical measuring instrument. What does it signify?
2. What is the purpose of the compound cross-slide stage on a toolmakers' microscope and on certain other optical measuring instruments?
3. List the advantages that the projection method of inspection has over mechanical methods for gaging work of a suitable nature.
4. What are the features common to all projection comparators?
5. Describe the two ways in which a projection comparator may be used to measure work.

11

MEASURING ANGLES AND TAPERS

A number of different tools may be used to measure angles accurately. Some of them are refinements of tools that were described in Chap. 5. Others are based on principles which were not touched on in that chapter.

Hardened-steel Square

A hardened-steel square, illustrated in Fig. 11.1, consists of a blade that is fixed in a beam. It is a precision-made tool, having

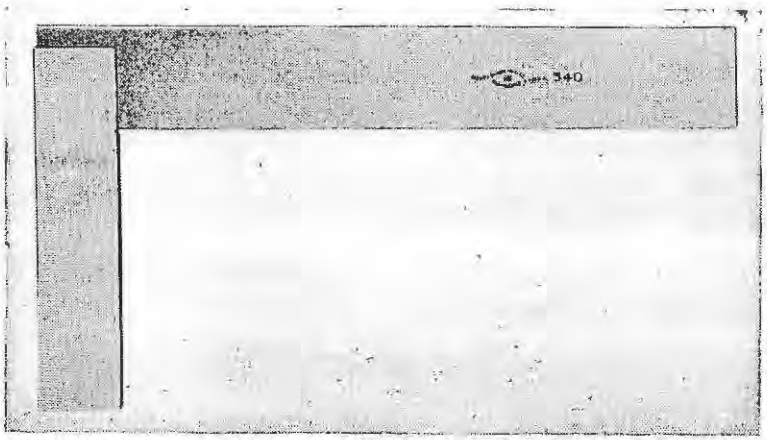


Fig. 11.1 Hardened-steel square. *Courtesy of Brown & Sharpe Mfg. Co.*

accurate right angles both inside and outside of the blade, that is used in toolmaking and other applications which require careful measurements of 90-deg angles. In using the square, it should be

held so that the face of the blade, and not a corner, contacts the work.

Toolmakers' Surface-plate Square

The toolmakers' surface-plate square, shown in Fig. 11.2, is designed to check the squareness of work that is set up on a surface plate. Both ends of the tool are square with its four edges so that either end may rest on the surface plate, and any of its edges may be used to test the work. This tool is useful for checking the accuracy of hardened-steel squares and similar tools.

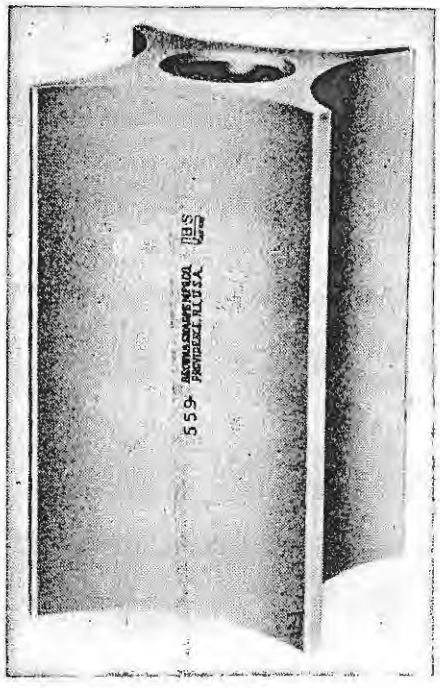


Fig. 11.2 Toolmakers' surface-plate square. *Courtesy of Brown & Sharpe Mfg. Co.*

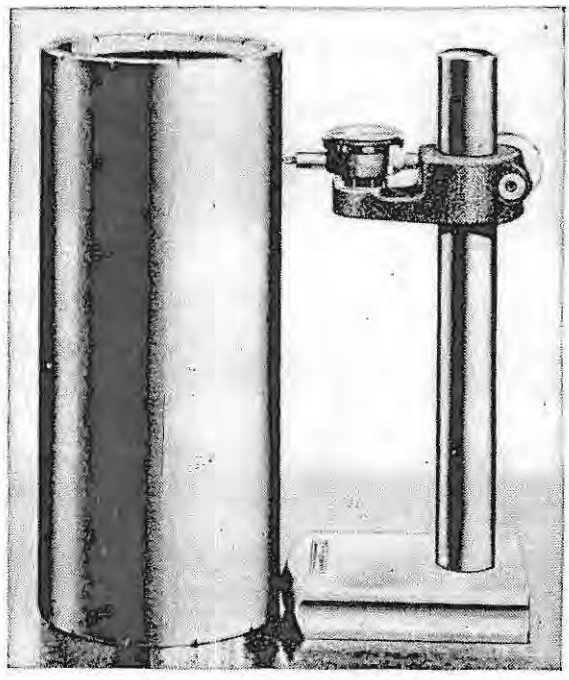


Fig. 11.3 Comparator-square. *Courtesy of The Taft-Pierce Manufacturing Company.*

Comparator Square and Cylindrical Square

The comparator square consists of a base, a column, and a dial-indicator unit that may be adjusted vertically on the column, and set to a cylindrical square, as illustrated in Fig. 11.3. Having been set to zero in this manner, the dial indicator will register errors in squareness of work being inspected to ten-thousandths of an inch.

The cylindrical square, also shown in Fig. 11.3, is a precision

cylinder whose ends are at 90 deg to its body. It is designed to provide a vertical reference line for work set up on a surface plate. These squares are made in sizes 4½, 8, and 12 in. high.

Universal Bevel Protractor

When angles of other than 90 deg must be inspected, an adjustable tool of some kind is usually employed to measure them.

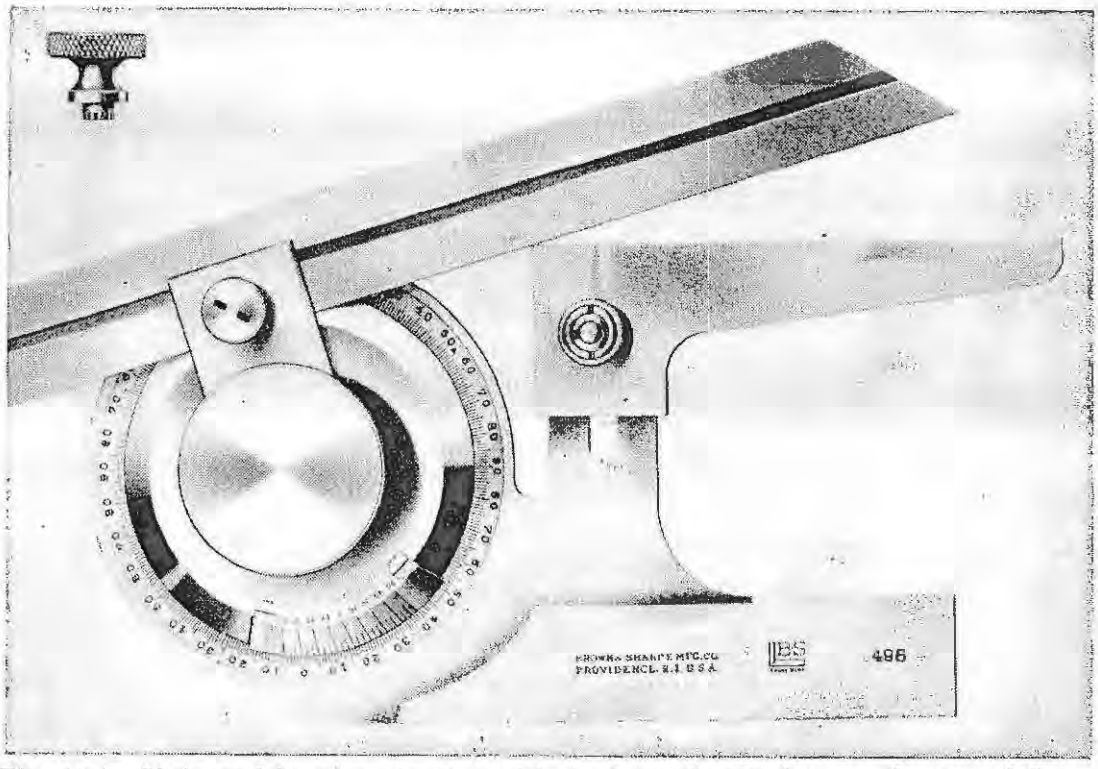


Fig. 11.4 Universal bevel protractor with acute-angle attachment. *Courtesy of Brown & Sharpe Mfg. Co.*

The universal bevel protractor, illustrated in Fig. 11.4, is an adjustable tool for measuring angles to 5 minutes or one-twelfth of a degree. The instrument consists of a dial that is combined with a fixed blade, to which measurements are referred, a swivel, and an adjustable blade. The dial, which is graduated in degrees for a full circle, reads to 180 deg each side of zero. The swivel turns on a central stud and may be locked at any angular setting of the adjustable blade by means of a large thumb nut. A vernier, which reads to 5 minutes, is attached to the swivel.

An enlarged view of the vernier and a portion of the dial are shown in Fig. 11.5.To read the instrument, start at zero on the dial

and read the number of degrees to zero on the vernier; then continue in the same direction on the vernier and read the number of minutes by locating that line on the vernier which coincides with a line on the dial. Each line that is counted on the vernier is read as 5 minutes. The reading in this example is 12 deg and 50 minutes.

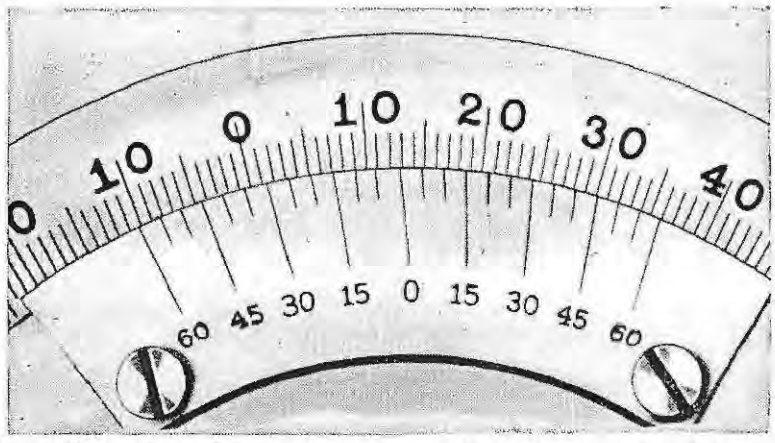


Fig. 11.5 Magnified view of the vernier and dial of a universal bevel protractor. The reading is 12 deg 50 minutes. *Courtesy of Brown & Sharpe Mfg. Co.*

Universal Angle Gages

The set of universal angle gages, shown at the top of Fig. 11.6, consists of seven parallel blades with a pair of supplementary angles at each end, three triangles, and three clamps. The gaging members may be assembled in various combinations to measure any angle from 0 to 180 deg in increments of 5 minutes with an error of not over 1 minute. When a combination has been assembled, the gages are clamped together for handling and use, as illustrated at the bottom of Fig. 11.6. The combination shown is arranged to measure an angle of 36 minutes.

Sine Bar

A sine bar is a tool that is used to measure angles accurately. It consists of a straightedge having two cylindrical disks or plugs located at or near its ends, as shown in Fig. 11.7. The plugs must be of the same diameter; their center line must be parallel to the working edge of the sine bar; and their center distance should, preferably, be an even number of inches apart. Center distances of sine bars in common use are 10 and 5 in.

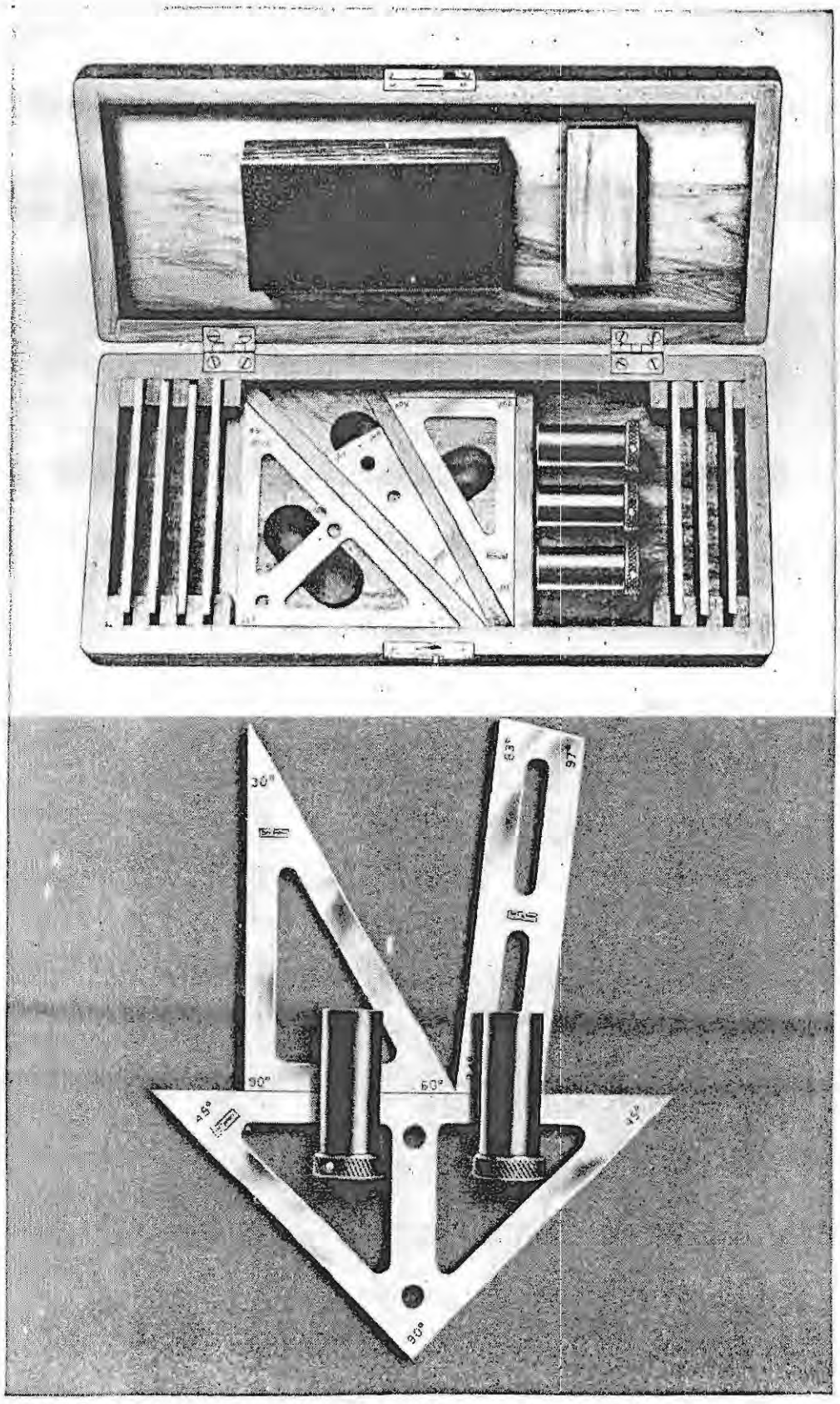


Fig. 11.6 Set of universal angle gages, and a combination of gages to produce an angle of 36 deg. *Courtesy of The Taft-Pierce Manufacturing Company.*

The sine bar is used with a surface plate and precision gage blocks, or alternate measuring equipment, to locate work for mechanical or inspection operations by raising one end of the bar above the plate to form a right-angle triangle, as illustrated in Fig. 11.8.

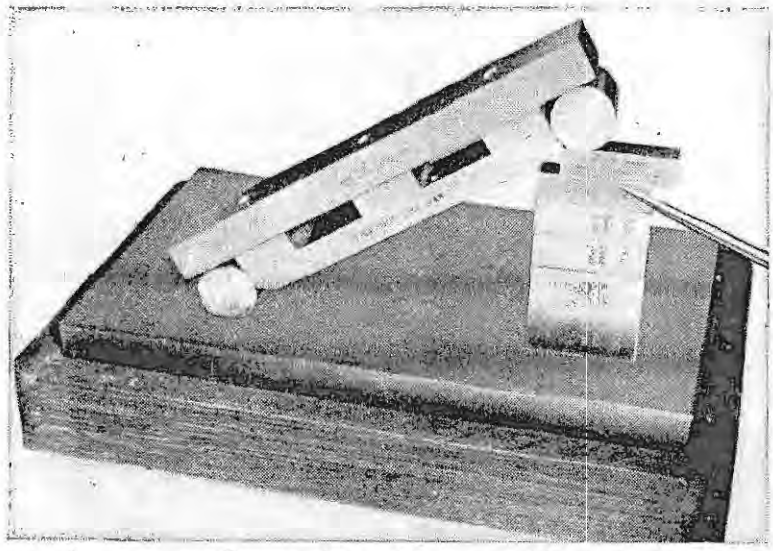


Fig. 11.7 A sine bar, master flat, and precision gage blocks in a setup to measure an angle. *Courtesy of The DoAll Company.*

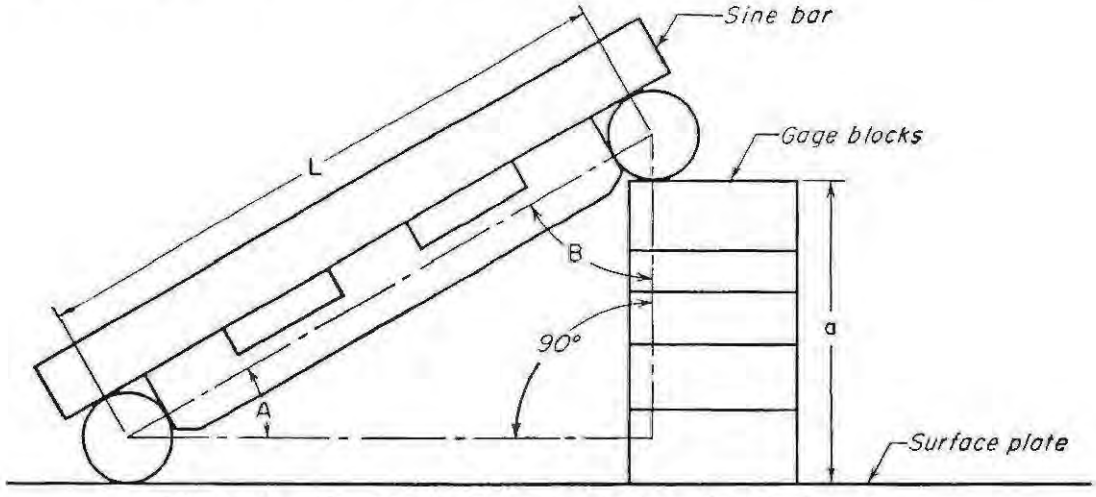


Fig. 11.8 Diagrammatic representation of a sine-bar setup.

One of two conditions will be encountered in using this tool.

1. Angle A, Fig. 11.8, will be given and dimension a will be required. Note that the sum of angles A and B is 90 deg, and A can be found if B is given.

To find dimension a when angle A is given, consult a table of trigonometric functions, locate the angle and the sine of the angle

in their respective columns, and multiply the sine of the angle by the length L of the sine bar. When a 10-in. sine bar is used, move the decimal point one place to the right to multiply by 10. When a 5-in. sine bar is used, move the decimal point one place to the right, and divide by 2.

To illustrate, assume that an angle of 31 deg is to be set up with a 10-in. sine bar. In Table 6, the sine of 31 deg is found to be 0.5150. Moving the decimal point one place to the right gives 5.150 as the required dimension. If a 5-in. sine bar were to be used, the dimension would be $5.150 \div 2 = 2.575$.

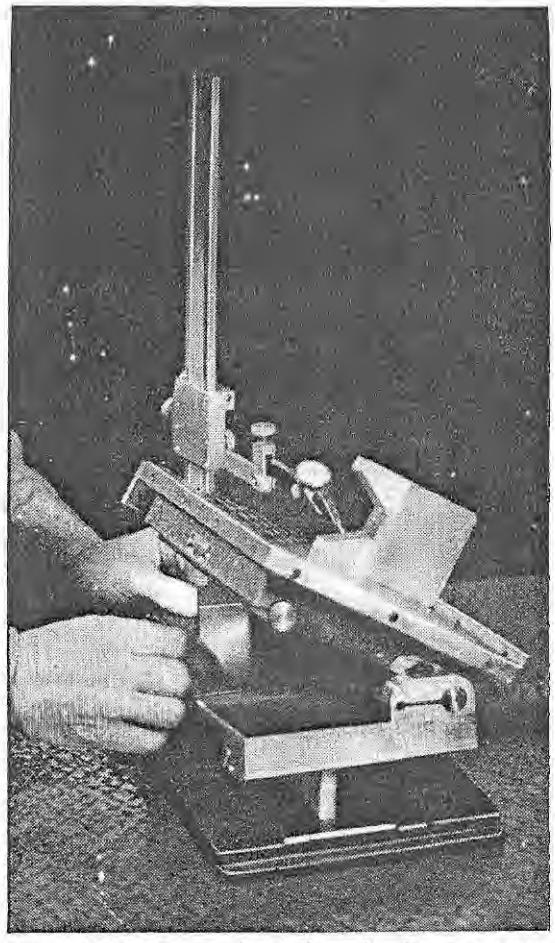


Fig. 11.9 Sine-plate for single- or compound-angle setups. *Courtesy of Omer E. Robbins Company.*

2. Dimension a will be given and angle A will be required. To find angle A when dimension a is given, divide dimension a by length L to obtain the sine of the angle. Then, in a table of trigonometric functions, find the corresponding angle. This, of course, is the reverse of the process described in (1) above.

Sine-bar tables that permit measurements to be determined for angles without the need for multiplying or dividing are published in machinists' handbooks.

Sine-bar fixtures

The sine plate, illustrated in Fig. 11.9, uses the sine-bar principle to make fast, accurate, angular setups in the shop and in inspection departments. Setups, difficult to make by other methods, are made quickly and easily by placing standard gage blocks between the roller and the base of the unit. The sine plate is built in two styles; the one shown is for

both single and compound angles, the other is for single angles only. Notice that the top plate contains a number of tapped holes to facilitate holding work. Similar equipment, called a Magna-Sine, for holding work by the attraction furnished by a magnetic chuck is produced by the same manufacturer.

The sine-bar principle is built into fixtures for testing work held on centers and also for work held on an integral surface plate.

Measuring Dovetails

Dovetails can not be measured directly with micrometers and verniers because the corners of these machine elements do not pro-

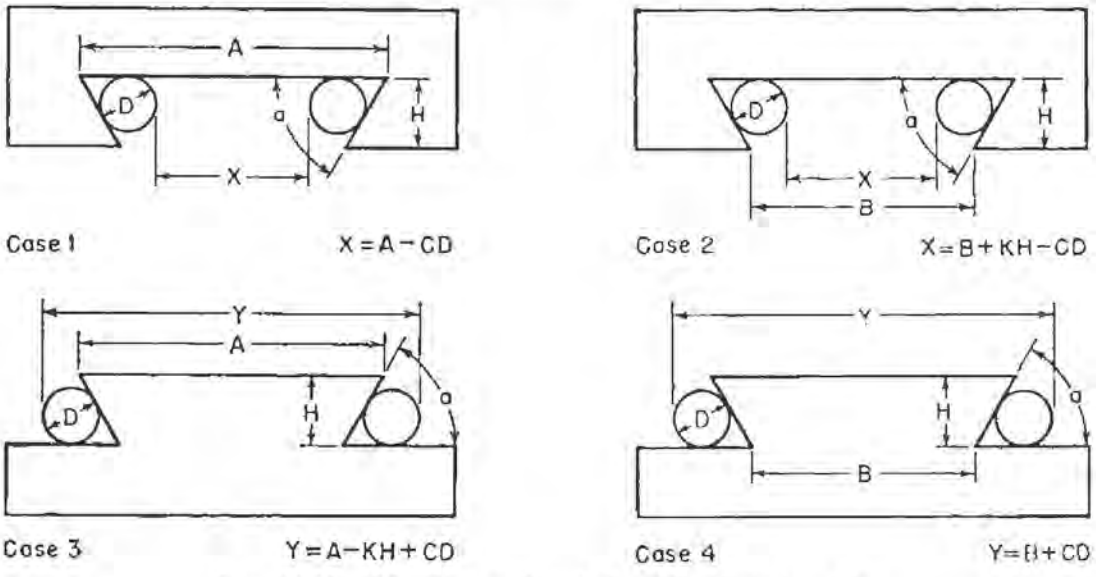


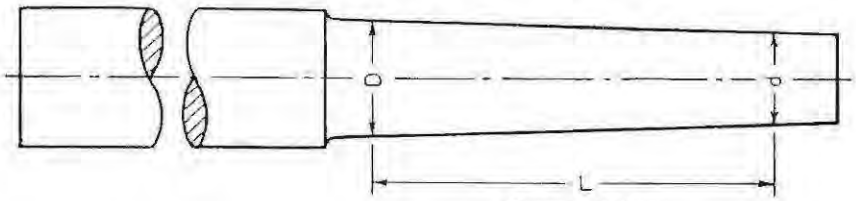
Fig. 11.10 Measuring dovetails with wires or rods.

vide reliable reference surfaces on which to base accurate measurements. One way of overcoming this difficulty is to measure over wires or rods that are placed in the dovetails, as shown in Fig. 11.10. These drawings illustrate different methods that may be used to dimension dovetail slots and tongues, and also illustrate the application of constants, given in Table 7, to determine the measurement over rods for each of the four cases which are shown.

Measuring Tapers

A *taper* is an object that diminishes in size gradually and uniformly toward a point to form a pyramid or cone. In industrial work, the word generally refers to a truncated cone.

A taper is dimensioned by specifying three of the four possible measurements indicated in Fig. 11.11. When any three of these four dimensions are given, the fourth may be found by substituting known values in the formulas given in Table 8.



D = large diameter
d = small diameter
L = length between diameters, measured parallel to the axis of the taper
T = taper per foot. A standard taper may be designated by number, or the taper per foot may be stated in a note. t = taper per inch = $\frac{T}{12}$
All dimensions in inches

Fig. 11.11 Dimensions specifying a taper.

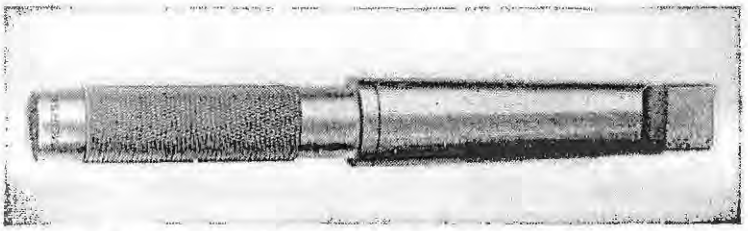


Fig. 11.12 Taper plug gage. *Courtesy of Morse Twist Drill and Machine Company.*

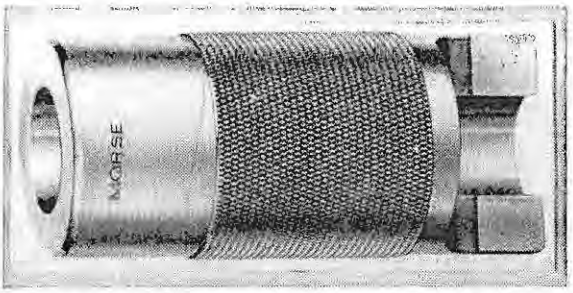


Fig. 11.13 Taper ring gage. *Courtesy of Morse Twist Drill and Machine Company.*

Tapers must be inspected for two things: the taper per foot and the comparative size of the taper. A taper plug gage, Fig. 11.12, is usually employed to check a taper hole; and a taper ring gage, Fig. 11.13, is used to measure a taper shaft.

To measure a taper shaft for taper per foot:

1. Draw three longitudinal lines about 120 deg apart on the tapered portion of the shaft with prussian blue or a similar marking compound.

2. Put the taper ring gage on the shaft and twist it slightly.
3. Remove the ring gage and examine the markings on the shaft. If the taper per foot is accurate, the lines will be rubbed along their full lengths. If it is inaccurate, however, they will be rubbed at one end and not at the other. This test, of course, shows if error is present and in which direction, but it does not tell the amount of error.

To check a taper shaft for size:

1. Put the taper ring gage on the shaft, as shown in Fig. 11.14, and examine the assembly to see if the shaft registers with the

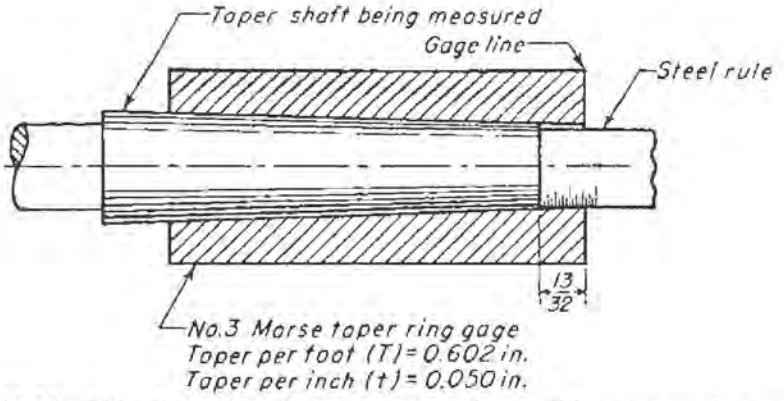

Taper shaft being measured
Gage line
Steel rule
13/32
No.3 Morse taper ring gage
Taper per foot (T) = 0.602 in.
Taper per inch (t) = 0.050 in.

Fig. 11.14 Checking the size of a taper shaft with a taper ring gage.

gage line. In this illustration, the end of the shaft should register with the end of the gage; i.e., the gage line. Therefore, the shaft is oversize.

2. To determine the error in size, measure the distance from the end of the work to the gage line with a steel rule. In this example, the measurement is $^{13}/_{32}$ in. Next, multiply this measurement by the taper per inch, in this case 0.050 in. The product, about 0.020 in. is the dimensional error of the taper.

A taper hole is measured with a taper plug gage in the same manner, with these two differences: first, the gage, rather than the work, is blued when checking the taper per foot; and second, the gage line will be at the large end of the gage.

The use of a sine bar and dial indicator to check the taper of a taper plug gage is illustrated in Fig. 11.15. This method may be applied in either of two circumstances: first, when the taper per

foot of the gage is known, and the combination of gage blocks needed to set the sine bar at the corresponding angle must be found; and second, when the height of the gage block combination is known, and the angular setting of the sine bar must be determined.

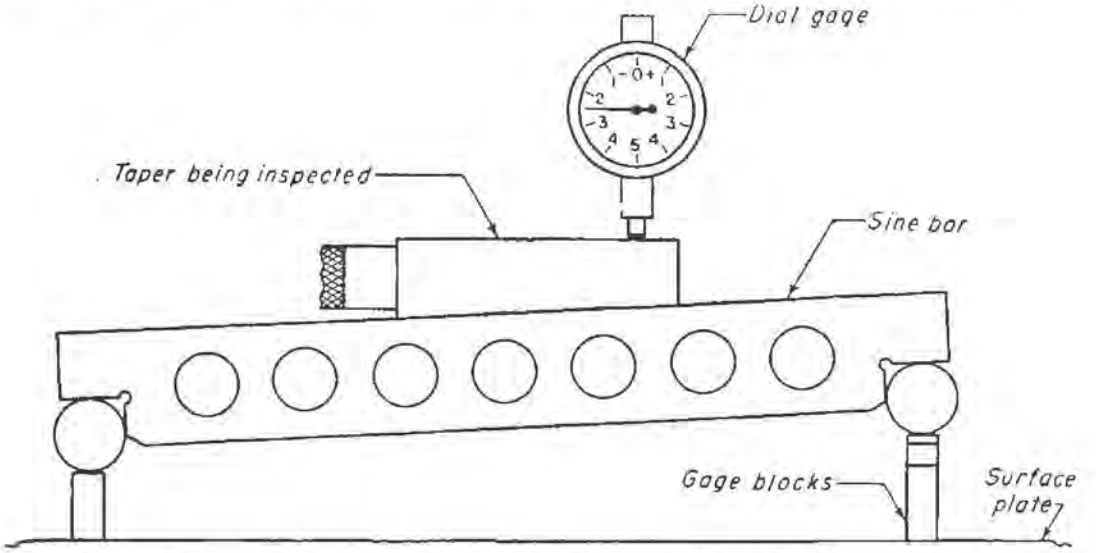


Fig. 11.15 Diagram of a sine bar set up to measure the angle of a taper plug gage.

The mathematical computations involved in the solutions of these problems are demonstrated below:

Case 1

Given: Taper per foot is $1\frac{11}{16}$ or 1.6875 in., and the length of the sine bar is 10 in.

To find: The included angle corresponding to the taper per foot, and the combination of gage blocks required to set the sine bar at that angle.

1. Find one-half of the taper per foot.

$$1.6875 \div 2 = 0.8437$$

2. Divide one-half of the taper per foot by 12.

$$0.8437 \div 12 = 0.0703$$

3. Find the angle with the center line. To do this, locate the nearest value to the quotient found above in the tangent column of Table 6. The nearest value to 0.0703 is 0.0699. This is the tangent of 4 deg.

4. Find the included angle.

$$2 \times 4^\circ = 8^\circ$$

5. Find the sine of the included angle in the column with that heading in Table 6.

$$\sin 8^\circ = 0.1392$$

6. Find the combination of gage blocks needed to set the sine bar at the included angle. To do this, multiply the sine of the included angle by the length of the sine bar.

$$0.1392 \times 10 = 1.392 = \text{the combination required}$$

Make the setup shown in Fig. 11.15, and move the dial indicator from one end of the taper to the other. The indicator hand will not move if the taper is correct; but it will change position if there is an error in the taper, and the dimensional error may be read on the dial gage.

If the angular error must be measured, proceed as directed in Case 2.

Case 2

Given: A taper plug gage, and the setup shown in Fig. 11.15.

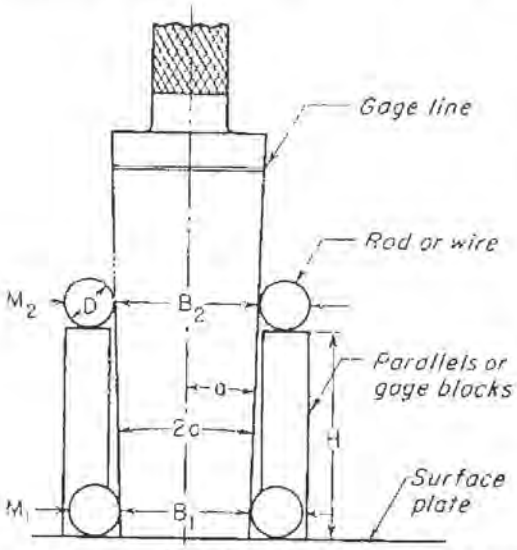
To find: The included angle of the gage.

1. Try different combinations of gage blocks in the setup until a check with the dial gage shows that the top of the taper is parallel to the surface plate.
2. Determine the dimension of the gage-block combination.
3. Divide the dimension by the length of the sine bar. The quotient is the sine of the angle to which the sine bar is set.
4. Find the angle by locating the sine in the column with that heading in a table of trigonometric functions.

Rods or wires may be used in the setup illustrated in Fig. 11.16 to measure the size and taper of a taper plug gage. The end of the gage must be square with its axis, and the height of the parallels or gage blocks should be an even number of inches to facilitate cal-

culations. Computations necessary to determine various dimensions are indicated beside the drawing.

Balls may be employed in a setup, as shown in Fig. 11.17, to check the angle of a taper ring gage. The depths from the end surface of the gage to the balls are measured with a micrometer depth



D = diameter of rods or wires;
H = height of parallels or gage blocks;
B_1, B_2 = diameters of the taper plug gage;
M_1, M_2 = measurements over rods or wires
T = taper per foot
a = angle with center line. $2a$ = included angle

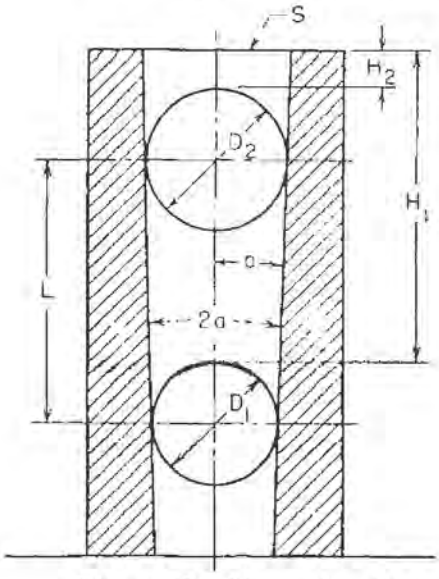
$$B_1 = M_1 - 2D$$

$$B_2 = M_2 - 2D$$

$$T = \frac{B_2 - B_1}{H} \times 12$$

$$a = \frac{T}{2 \times 12}$$. Look up quotient in tangent column in a table of trigonometric functions to find the angle.

Fig. 11.16 Measuring a taper plug gage with rods or wires.



S = end surface of gage;
D_1, D_2 = diameters of balls;
H_1, H_2 = measurements from end surface to balls;
L = center distance of balls;
a = angle with center line; $2a$ = included angle

$$L = H_1 + \frac{D_1}{2} - \left(H_2 + \frac{D_2}{2}\right)$$

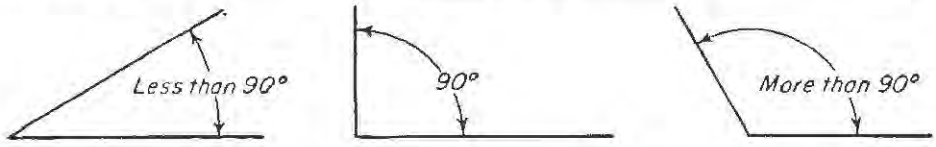
$$a = \frac{D_2 - D_1}{2L}$$. Look up quotient in sine column in a table of trigonometric functions to find the angle.

Fig. 11.17 Measuring the angle of a taper ring gage with the aid of balls.

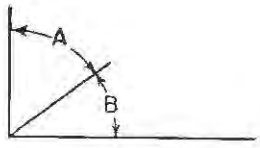
gage or other suitable tool. Computations for determining the angle are indicated with the diagram.

Shop Trigonometry

Trigonometry was used to compute dimensions and angles required to inspect work with the sine bar and other tools that have



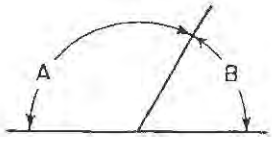
Acute Angle | Right Angle | Obtuse Angle



Two angles whose sum is 90° are called complementary angles.

$A + B = 90°$

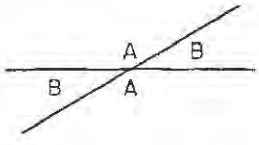
A is the complement of B, and vice versa.



Two angles whose sum is 180° are called supplementary angles.

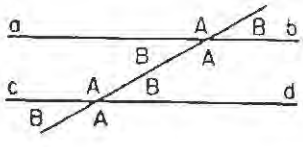
$A + B = 180°$

A is the supplement of B, and vice versa.



When two lines intersect, the opposite angles that are formed by the intersecting lines are equal.

$A = A$, $B = B$

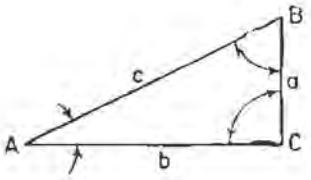


When a line intersects two parallel lines, the opposite angles that are formed by the intersecting line and parallel lines are equal.

Lines *ab* and *cd* are parallel.

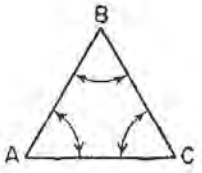
Angles A are equal, and angles B are equal.

Fig. 11.18 Angles and triangles.



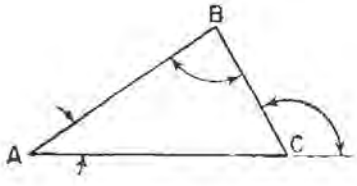
A triangle is a closed figure that is bounded by three lines or sides which intersect at points to form three angles.

It is customary to designate the angles of a triangle by using upper case letters *A*, *B*, *C*, etc.; and to designate the sides opposite the angles by using the corresponding lower case letters *a*, *b*, *c*, etc.



The sum of the three angles of a triangle is 180°.

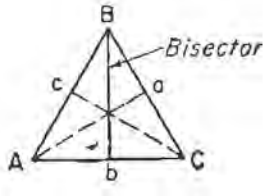
Angles $A + B + C = 180°$



If one side of a triangle is produced, the exterior angle that results is equal to the sum of the two opposite interior angles.

Angle C = Angles $A + B$

Equilateral Triangle



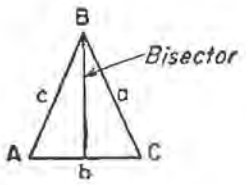
An equilateral triangle has three equal sides and three equal (60°) angles. A line that bisects any of its angles bisects the side opposite that angle, is perpendicular to the side, and divides the equilateral triangle into two equal 30° and 60° right triangles.

Sides *a*, *b*, and *c* are equal.

Angles *A*, *B*, and *C* are equal.

Fig. 11.18 Angles and triangles (*Continued*)

Isosceles Triangle

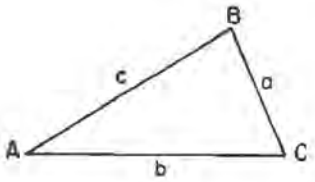


An isosceles triangle has two equal sides, and two equal acute angles opposite the equal sides. A line that bisects the unequal angle bisects the unequal side opposite the angle, is perpendicular to the side, and divides the isosceles triangle into two equal right triangles.

Side a = side c.

Angle A = angle C.

Scalene Triangle

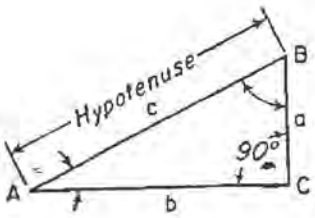


In a scalene triangle, no two sides are equal, and no two angles are equal.

In any triangle, the longest side is opposite the largest angle; and, conversely, the largest angle is opposite the longest side, and so on.

Side c is opposite angle C.

Right Triangle



A right triangle has one 90° angle. The sum of the other two angles, therefore, is 90° and they are acute angles.

Angle C = 90°

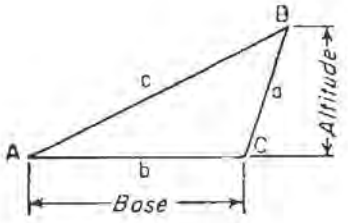
Angle A + Angle B = 90°

The side of a right triangle opposite to the right angle is called the hypotenuse.

Side c is the hypotenuse

Fig. 11.18 Angles and triangles (*Continued*)

Obtuse-angled Triangle



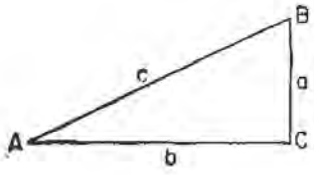
An obtuse-angled triangle has one angle greater than 90°.

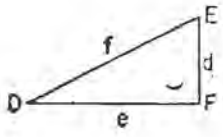
Angle C is greater than 90°

Any side of a triangle may be regarded as its base.

The perpendicular distance from the base of a triangle to the vertex of the opposite angle is its altitude.

Similar Triangles



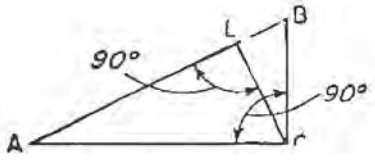


When the angles of two triangles are equal, the triangles are similar and their corresponding sides are in proportion.

Angles $A = D$, $B = E$, $C = F$

Side $a:d::b:e::c:f$

The perpendicular from the hypotenuse of a right triangle to the vertex of the right angle divides the triangle into two right triangles that are similar to each other and to the original triangle.



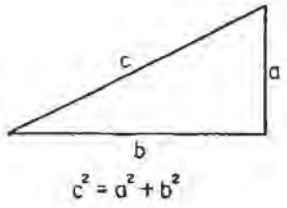
Line DC is perpendicular to hypotenuse AB

Angle ACB = Angle ADC = Angle CDB

Angle ABC = Angle ACD = Angle CBD

Angle CAB = Angle DAC = Angle DCB

Fig. 11.18 Angles and triangles (*Continued*)



The square of the hypotenuse of a right triangle is equal to the sum of the squares of the other two sides.

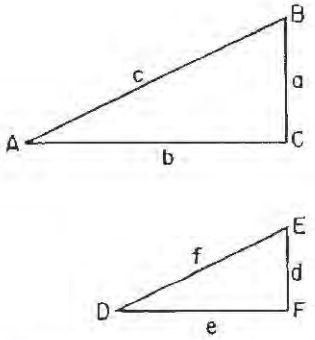
Application of this proposition will involve the finding of squares and square roots. The use of handbook tables of squares and square roots is the easiest way to work such problems. If tables are not available, the problems must be worked by involution and evolution.

Fig. 11.18 Angles and triangles (*Continued*)

been described by giving formulas and written directions for its application. A more extensive knowledge of trigonometry, however, will be valuable to inspectors for solving many other problems that may occur in connection with the measurement of angles. For those who do not have the opportunity to study the subject formally, a brief statement of some principles of plane geometry and trigonometry may be helpful.

A *triangle* is a geometrical figure made up of three sides and three angles, as shown in various drawings of Fig. 11.18. The most important angle in shop work is the right angle; and statements and illustrations in Fig. 11.18 show how right angles may be constructed when dimensions are given, originally, for other kinds of triangles.

Trigonometry employs numerical values of given parts of triangles to compute unknown parts by using relations that exist between the sides and angles of triangles. In Fig. 11.19, the illustration of similar triangles is repeated to emphasize that their corresponding sides are proportional, and to point out that the ratio of the lengths of any two sides of a right triangle is constant for given complementary acute angles regardless of the size of the triangle. Ratios like those shown in Fig. 11.19 are called "functions" of angles, and the six possible ratios or trigonometric functions of an angle are called the sine, cosine, tangent, cotangent, secant, and cosecant. These may be expressed as formulas as illustrated in Fig.



When the angles of two triangles are equal, the triangles are similar and their corresponding sides are proportional:

$$\text{Angles } A = D,\ B = E,\ C = F$$
$$\text{Side } a:d::b:e::c:f$$

The ratio of the lengths of any two sides of a right triangle is constant for a given angular relation regardless of the size of the triangle. For example, with respect to angles A and D above:

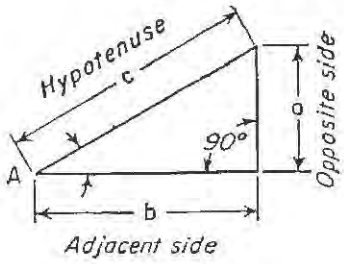
$$\frac{a}{c} = \frac{d}{f}$$
$$\frac{b}{c} = \frac{e}{f}$$
$$\frac{a}{b} = \frac{d}{e}, \text{ etc.}$$

Fig. 11.19 Similar triangles.

11.20. Their numerical values have been computed for angles and arranged in tables of trigonometric functions similar to Table 6. These tables vary in detail according to the accuracy required in the solution of problems. Tables to five decimal places for angles in degrees and minutes are given for the six functions in engineers' and machinists' handbooks.

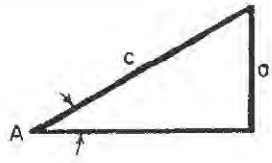
Two kinds of shop problems are solved by the use of trigonometry.

1. The lengths of two sides, or of one side and the hypotenuse of a right triangle are known; and it is required to find the magnitude of one of its acute angles, neither of which is given. Recall that the

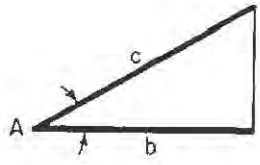


Sides of a Right Triangle

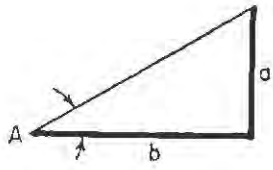
The sides of a right triangle, named in relation to angle A in this figure, are: side a, the opposite side; side b, the adjacent side; and side c, the hypotenuse.



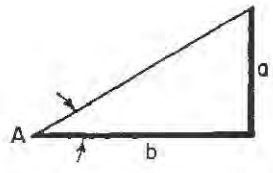
$$\text{Sine } A = \frac{\text{opposite side}}{\text{hypotenuse}} \qquad \sin A = \frac{a}{c}$$



$$\text{Cosine } A = \frac{\text{adjacent side}}{\text{hypotenuse}} \qquad \cos A = \frac{b}{c}$$

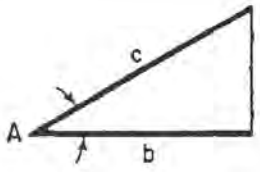


$$\text{Tangent } A = \frac{\text{opposite side}}{\text{adjacent side}} \qquad \tan A = \frac{a}{b}$$

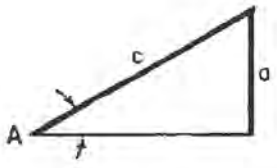


$$\text{Cotangent } A = \frac{\text{adjacent side}}{\text{opposite side}} \qquad \cot A = \frac{b}{a}$$

Fig. 11.20 Trigonometric functions.



$$\text{Secant } A = \frac{\text{hypotenuse}}{\text{adjacent side}} \qquad \sec A = \frac{c}{b}$$



$$\text{Cosecant } A = \frac{\text{hypotenuse}}{\text{opposite side}} \qquad \csc A = \frac{c}{a}$$

Fig. 11.20 Trigonometric functions (*Continued*)

sum of the acute angles of a right triangle is 90 deg, and that if one is known, the other may be found by subtraction.

2. The magnitude of one acute angle and the length of one side or the hypotenuse are known; and it is required to find the length of the other side, or the hypotenuse, or both. Recall that the square of the hypotenuse of a right triangle is equal to the sum of the squares of the other two sides; and if two of these lengths are known, the other may be found by applying this proposition.

Several variations of each type of problem stated above are possible.

To apply trigonometry to the solution of shop problems:

1. Analyze the job and its specifications. If the problem cannot be solved directly from information that is given, find a needed angle or construct a right triangle by one of the methods indicated in Fig. 11.18.
2. Determine if an acute angle, a side, or the hypotenuse must be found.
3. Determine which function, described in connection with Fig. 11.20, may be used to solve the problem.
4. Substitute numerical values in the proper formula and solve for the missing element.

Figure 11.21 illustrates a problem in which an acute angle of a right triangle is to be found. Analysis of the diagram shows that the

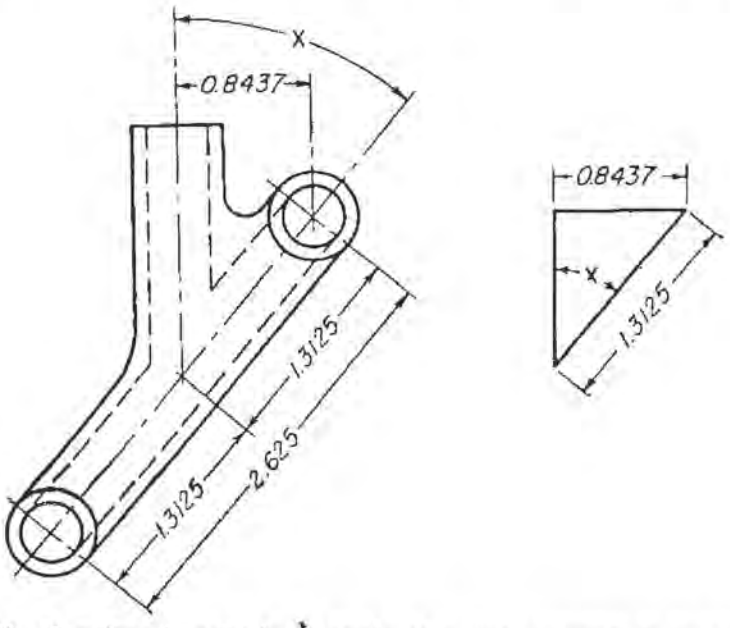
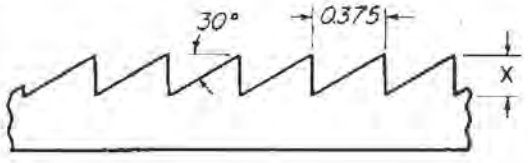


Fig. 11.21 Problem in which an angle of a right triangle is to be found.

hypotenuse and the side opposite the unknown angle are given. Examination of Fig. 11.20 shows that the formula for the sine of the angle may be used to solve this problem.

$$\sin x = \frac{\text{opposite side}}{\text{hypotenuse}} = \frac{0.8437}{1.3125}$$

$$\frac{0.8437}{1.3125} = 0.6428+$$



Find 0.6428 in the sine column of Table 6. This value is seen to be the sine of 40 deg. Therefore

Angle $x = 40°$ *Ans.*

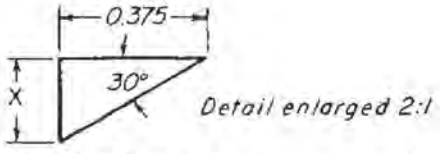


Fig. 11.22 Problem in which a side of a right triangle is to be found.

Figure 11.22 illustrates a problem in which one side of a right triangle is to be found. Analysis of the drawing shows that an acute angle and its adjacent side are given, and that the unknown side is opposite the known angle. Reference to Fig. 11.20 shows that the formula for the tangent may be used to solve this problem.

$$\tan 30^\circ = \frac{\text{opposite side}}{\text{adjacent side}}$$

Find 30 deg in the angle column of Table 6, and find 0.5774 opposite 30 deg in the tangent column. Then

$$0.5774 = \frac{x}{0.375}$$

$$x = 0.5774 \times 0.375 = 0.2165$$

$$\textit{Side } x = 0.2165 \qquad \textit{Ans.}$$

Universal Dividing Head[1]

The universal dividing head is a high-precision milling-machine accessory that is regularly employed in machine-shop work and in the inspection department to check the accuracy of machined parts.

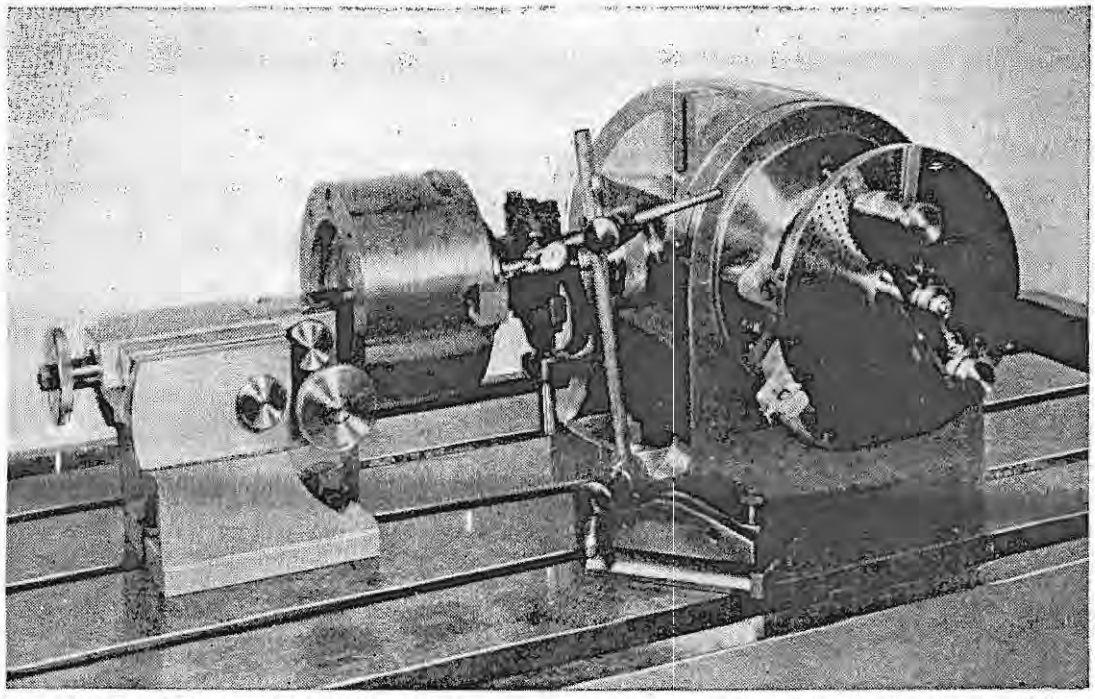


Fig. 11.23 Universal dividing head set up on an inspection table to check parallelism and alignment of two keyways in a dolly. From "A Treatise on Milling and Milling Machines," *courtesy of The Cincinnati Milling Machine Co.*

It is often used to check the contour of cams, and the angular spacing of holes, gear teeth, notches and other machined surfaces on work that may be mounted conveniently on the dividing head.

[1] Courtesy The Cincinnati Milling Machine Co.

Examples of the use of the dividing head to inspect machine parts follow:

Example 1. Checking Parallelism and Alignment

The example shown in Fig. 11.23 illustrates a universal dividing head that is set up on an inspection table to check the parallelism and alignment of the keyways in a dolly for holding an impeller. The keyways in the dolly, as shown in Fig. 11.24, must be parallel

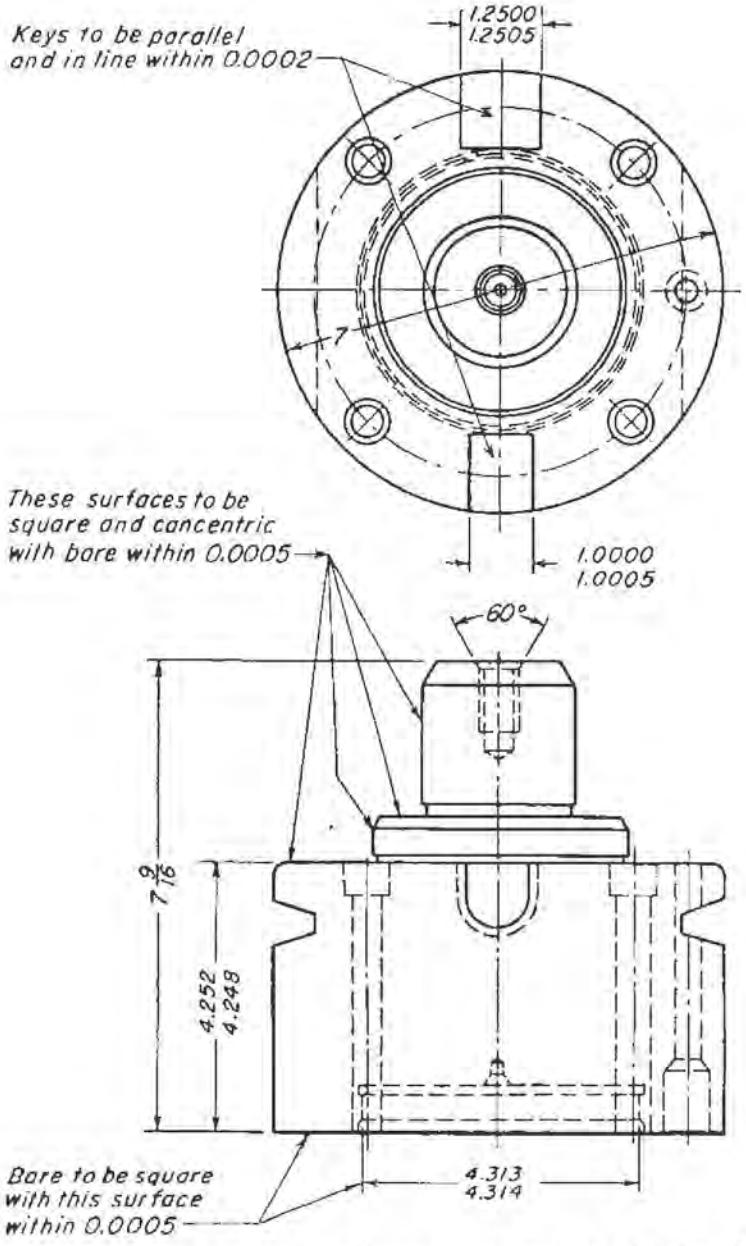


Fig. 11.24 Drawing showing dimensional accuracy required in the alignment and parallelism of the keyways in a dolly. From "A Treatise on Milling and Milling Machines," *courtesy of The Cincinnati Milling Machine Co.*

and in line with each other to within 0.0002 in. To check for parallelism, the dolly is placed between centers of the dividing head and tailstock, and gage blocks are inserted in the keyways. The dial indicator is set to read on the gage blocks inserted in one of the keyways, for example, that one having a nominal width of 1.250 in. Set the first keyway parallel to the inspection table by rotating the dolly manually and checking with the indicator until the same reading is obtained as it is moved radially along the gage block.

The dolly is now clamped to the dividing-head spindle by means of the driving dog and is then indexed 180 deg to bring the second keyway into position. Since the thickness of the gage blocks for the second keyway is only 1.000 in., it is necessary to lay a $\frac{1}{8}$-in. thick gage block on top of the one already inserted in this keyway to make up for the difference in the width of the two keyways. The indicator stem is then moved radially on the surface of the gage blocks, as before, to check the parallelism of the keyways. If the indicator does not change when it is moved in a radial direction, it shows that the second keyway is parallel with the first. A deviation of this reading from the reading on the first keyway, taken at a point on the gage block corresponding to the 7-in. diameter, indicates the amount by which the two keyways are out of parallelism. This should not exceed 0.0002 in.

Example 2. Checking a Cam Profile

To check the accuracy of a cam profile, the dividing head is used in conjunction with a cam measuring fixture. The latter consists of a plunger carrying a roller of the required diameter to engage the cam surface, and a micrometer for measuring the displacement of the plunger in relation to the angular displacement of the cam. This setup is shown in Fig. 11.25, and the dimensions of the cam are given in Fig. 11.26.

The variations N of the cam profile over the base circle of 2.2295-in. radius are listed in a separate table, not shown, for every degree of cam surface. Indexing for each half degree is obtained by moving the index pin three spaces in the 54-hole circle on the index plate, starting at the low point on the cam surface.

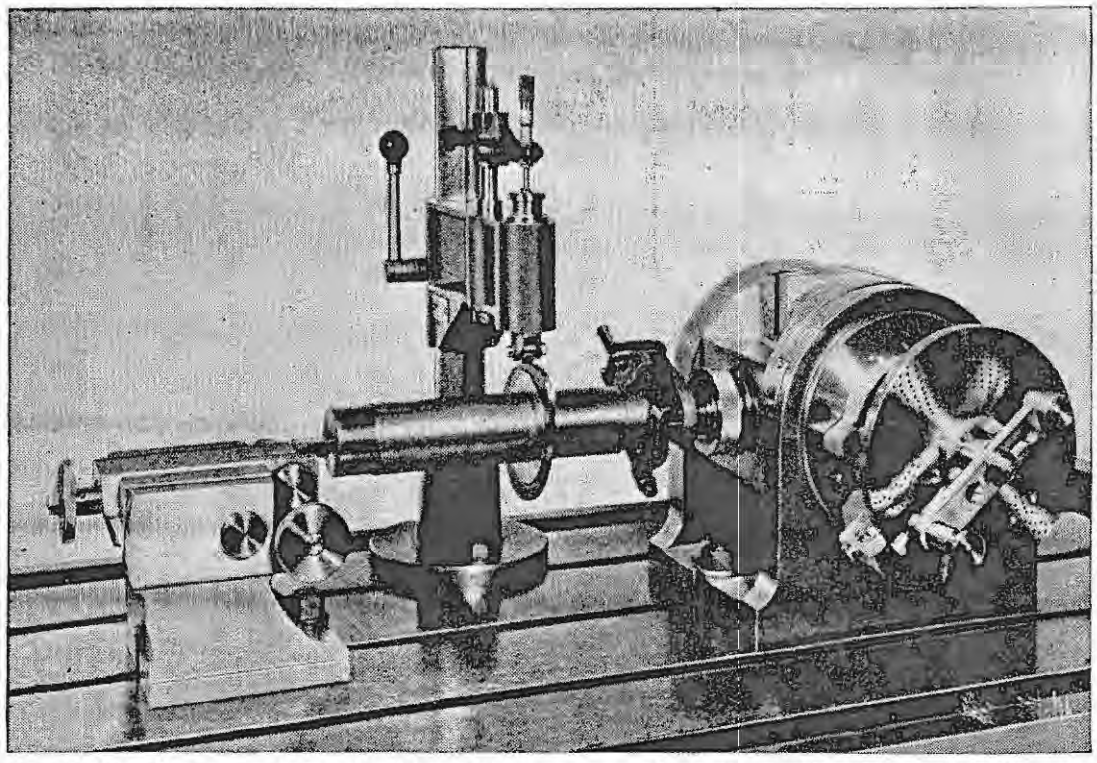


Fig. 11.25 Setup used in checking the accuracy of a cam profile. From "A Treatise on Milling and Milling Machines," *courtesy of The Cincinnati Milling Machine Co.*

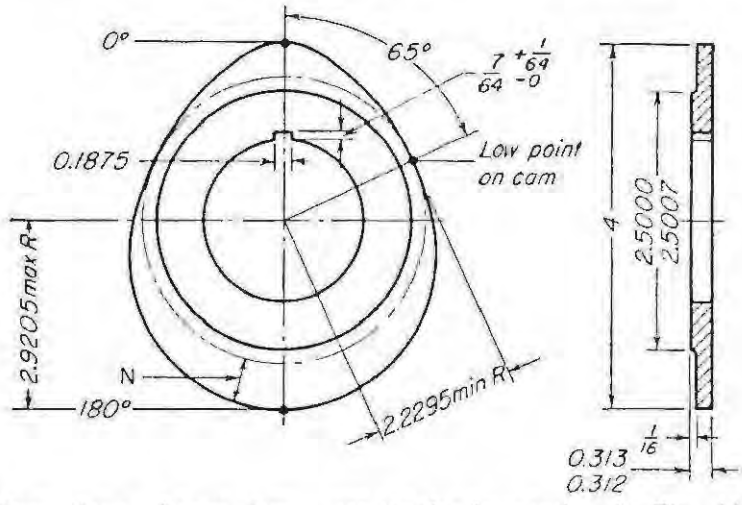


Fig. 11.26 Dimensions of cam shown set up for inspection in Fig. 11.25. From "A Treatise on Milling and Milling Machines," *courtesy of The Cincinnati Milling Machine Co.*

The axis of the keyway is in line with the high points of the cam. One of the low points of the cam is accurately located by setting the axis in a vertical position and then indexing 65 deg. This will locate the low point under the cam roller. The micrometer is set to zero reading at this point and is withdrawn before indexing. To

take the readings N, the micrometer stem is lowered to contact the plunger carrying the roller. These readings are checked against the values listed in the table of the original drawing.

The angular indexing of work with a standard 40:1 gear-ratio dividing head is accomplished by means of the gear train and other parts shown in simplified form in Fig. 11.27. From this diagram, it may be concluded that it takes 40 turns of the index crank to turn

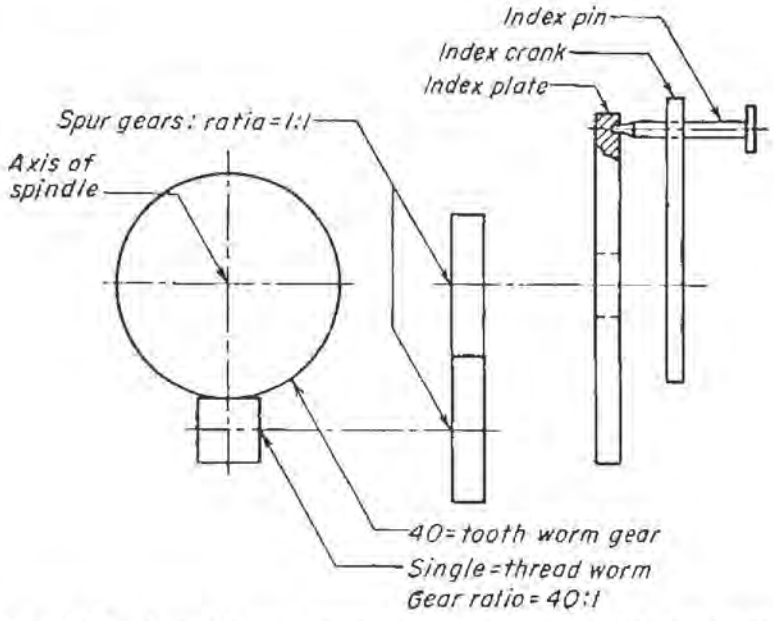


Fig. 11.27 Simplified diagram of gearing in a dividing head.

the spindle of the dividing head once. The formula for computing the movement of the index crank to give a required movement of the spindle, therefore, may be stated as follows:

$$\frac{40}{N} = \text{movement of index crank}$$

where 40 = number of teeth in the worm gear on the spindle of the dividing head, and N = number of divisions to be indexed.

The indexing movement required to inspect the two keyways 180 deg apart, shown in Fig. 11.23, is

$$\frac{40}{2} = 20 \text{ whole turns of the index crank}$$

The process of indexing an angle, dimensioned in degrees, minutes, and seconds, is called *angular indexing*. The indexing movement required to index 1 deg or $\frac{1}{360}$ of a circle is

$$\frac{40}{360} = \frac{1}{9} \text{ turn of the index crank}$$

Fractional movements of the index crank are measured by using concentric circles of holes that are drilled in the index plate. The standard index plate furnished with the Cincinnati dividing head is drilled on both sides and has circles of holes as follows:

First side: 24, 25, 28, 30, 34, 37, 38, 39, 41, 42, 43.

Second side: 46, 47, 49, 51, 53, 54, 57, 58, 59, 62, 66.

The 54-hole circle in the second side of the index plate is evenly divisible by 9; therefore, a movement of $\frac{1}{9} \times 54 = 6$ holes in the 54-hole circle will index 1 deg. Since there are 60 minutes in 1 deg, a movement of 1 hole in the 54-hole circle will index 10 minutes or $\frac{1}{6}$ of a degree, 2 holes will index 20 minutes or $\frac{1}{3}$ of a degree, and 3 holes will index 30 minutes or $\frac{1}{2}$ of a degree.

The Brown & Sharpe Mfg. Co. furnishes three index plates with its dividing head which are drilled with circles of holes as follows.

Plate 1: 15, 16, 17, 18, 19, 20.

Plate 2: 21, 23, 27, 29, 31, 33.

Plate 3: 37, 39, 41, 43, 47, 49.

The 18-hole circle is evenly divisible by 9, and may be used to index degrees and one-half degrees; and the 27-hole circle is evenly divisible by 9, and may be used to index degrees and one-third degrees.

To compute the indexing movement required to index 1 minute, divide 40 by 21,600; and to index seconds, divide 40 by 1,296,000. Indexing movements that can not be obtained with regular dividing-head equipment may be secured by using a high-number indexing attachment, a wide-range divider, differential indexing, or a dividing head having a special gear ratio. Angular indexing tables and descriptions of special methods are published in machinists' handbooks.

Optical Dividing Head

The optical dividing head is an instrument that provides for accurate angular settings by means of a graduated glass dial, mounted directly on the spindle, which is read through a microscope.

The dial on the optical dividing head shown in Fig. 11.28 is graduated on a circle having a range of 0 to 360 deg. The main circle is divided directly into 20 minutes, and the reading on this circle is in 5 seconds through the use of a superimposed optical ver-

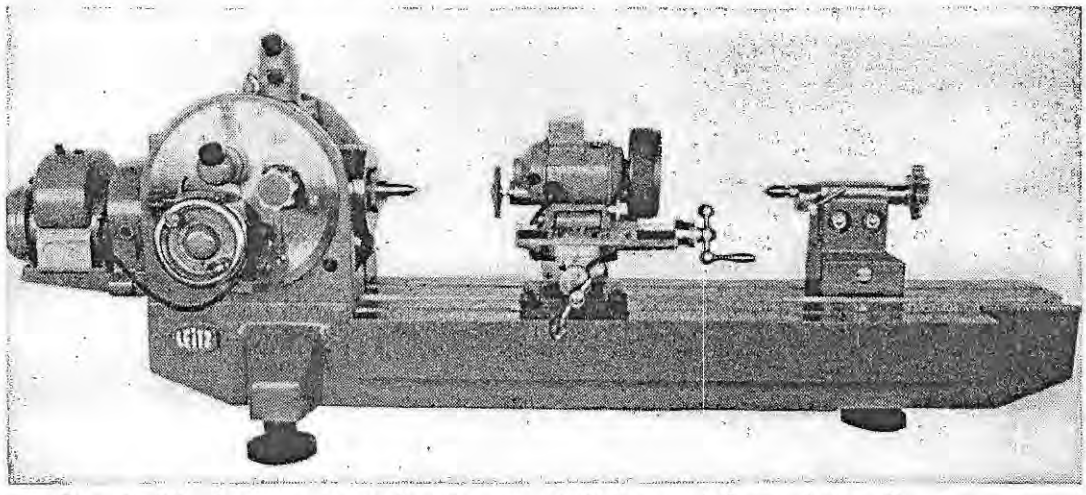


Fig. 11.28 Leitz optical dividing head. *Courtesy of George Scherr Co., Inc.*

nier. Readings are made with a microscope having 180-deg double displaced-microscope tubes to eliminate indexing errors from eccentricity.

A handwheel provides for coarse settings of the spindle, and a worm wheel on front of the head provides for fine adjustments. A double brake locks the spindle in place when it has been set. A motor drive for the main spindle is available and may be used optionally to speed up operations in addition to rotation by hand. It may also be used for finishing precision parts in the dividing head by grinding and for other machining operations.

The body of the dividing head, which contains the spindle elements, may be tilted up to 110 deg and locked in place by double brakes.

The dividing head, footstock, and any inspection fixtures required to measure work are mounted on a base plate having a three-point suspension.

QUESTIONS

1. Describe a cylindrical square and the manner in which it is used to inspect 90-deg angles.

2. Describe a universal bevel protractor and the manner in which the tool is read.

3. What is a sine bar? How is it used to measure angles?

4. What is a taper? How are tapers dimensioned?

5. Describe the method of testing a taper shaft with a taper ring gage to see if the taper per foot is correct.

6. A taper shaft that is oversized must move $\frac{5}{8}$ in. for its end to register with the gage line on the taper ring gage. If the taper per foot is 0.623 in., how much is the diameter of the shaft oversized?

7. What indexing movement is required to index an angle of 1 deg on a standard 40:1 gear-ratio dividing head? Express the answer as a fractional turn of the index crank.

12

MEASURING SCREW THREADS

A *screw* is a cylinder that has a helical groove cut in it, or a cone that has a conical spiral groove cut in it to form a ridge which is called a *thread*. When the thread is formed on the outside of a part, it is called an *external thread*, and when it is formed inside of a hole it is called an *internal thread*. Externally threaded parts are bolts or screws, and internally threaded parts are threaded holes or nuts. Screws and nuts are employed as fasteners, to transmit power and motion, to make adjustments, to make leak-proof joints, and as components of measuring devices.

Thread Forms

Different thread forms that have been developed to meet the requirements of the various applications listed above are illustrated in Figs. 12.1(*a-f*) and 12.2(*a-f*). The V-form thread (Fig. 12.1*a*) is used for some threads in boiler-making practice. The American National Standard form of thread, Fig. 12.1*b*, is used for bolts, nuts, machine screws, and threaded parts; the Whitworth form of thread, Fig. 12.1*c*, is the British standard for the same service; and the Unified Standard form of thread, Figs. 12.1*d* and *e*, is one that has been adopted by the United Kingdom, Canada, and the United States to secure interchangeability in the threaded products of the three nations. The thread forms illustrated in Figs. 12.1*f* to 12.2*f*,

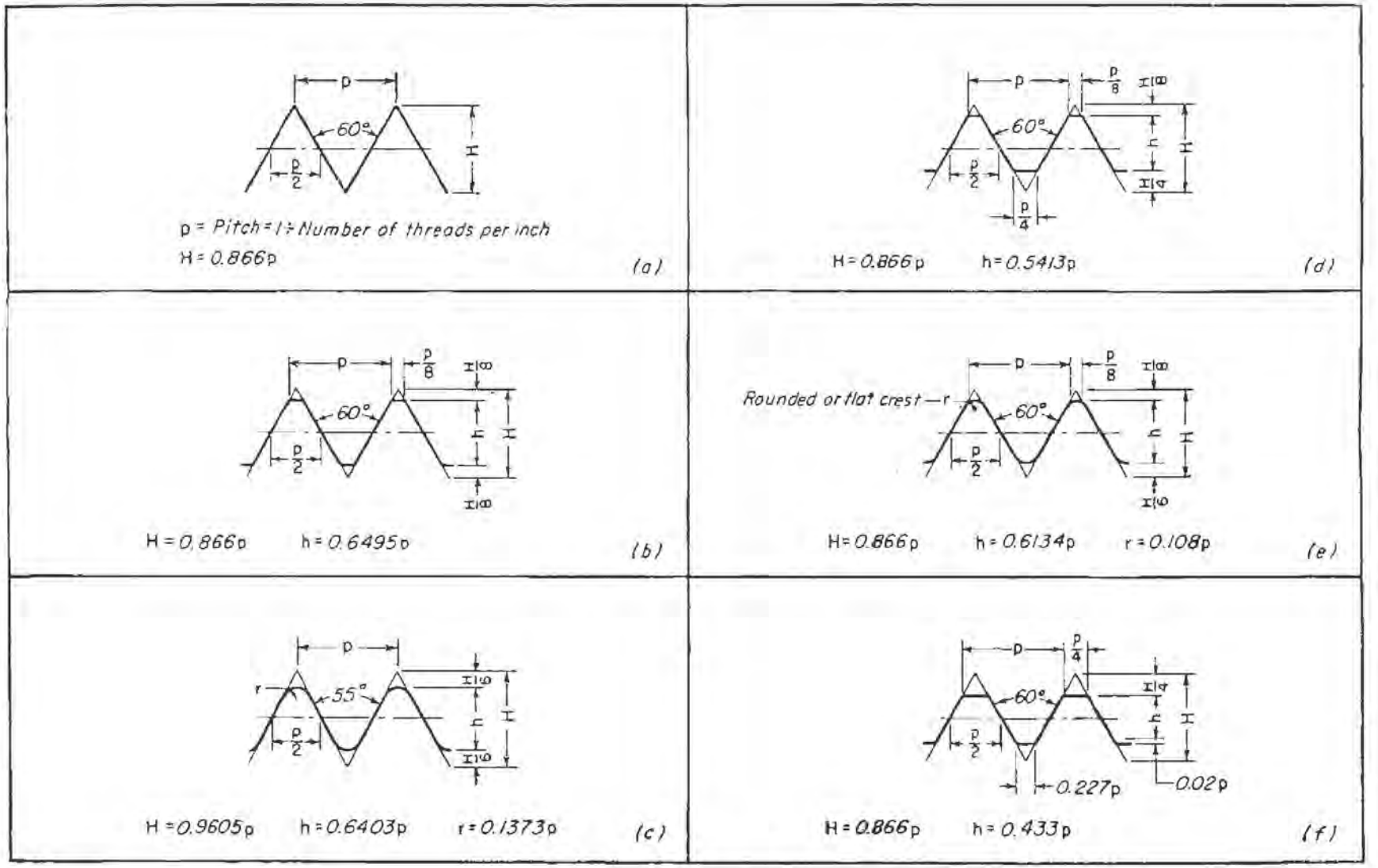


Fig. 12.1 (*a*) V thread; (*b*) American National Standard thread; (*c*) Whitworth Standard thread; (*d*) Unified Standard thread—nut; (*e*) Unified Standard thread—screw; (*f*) 60-deg stub thread.

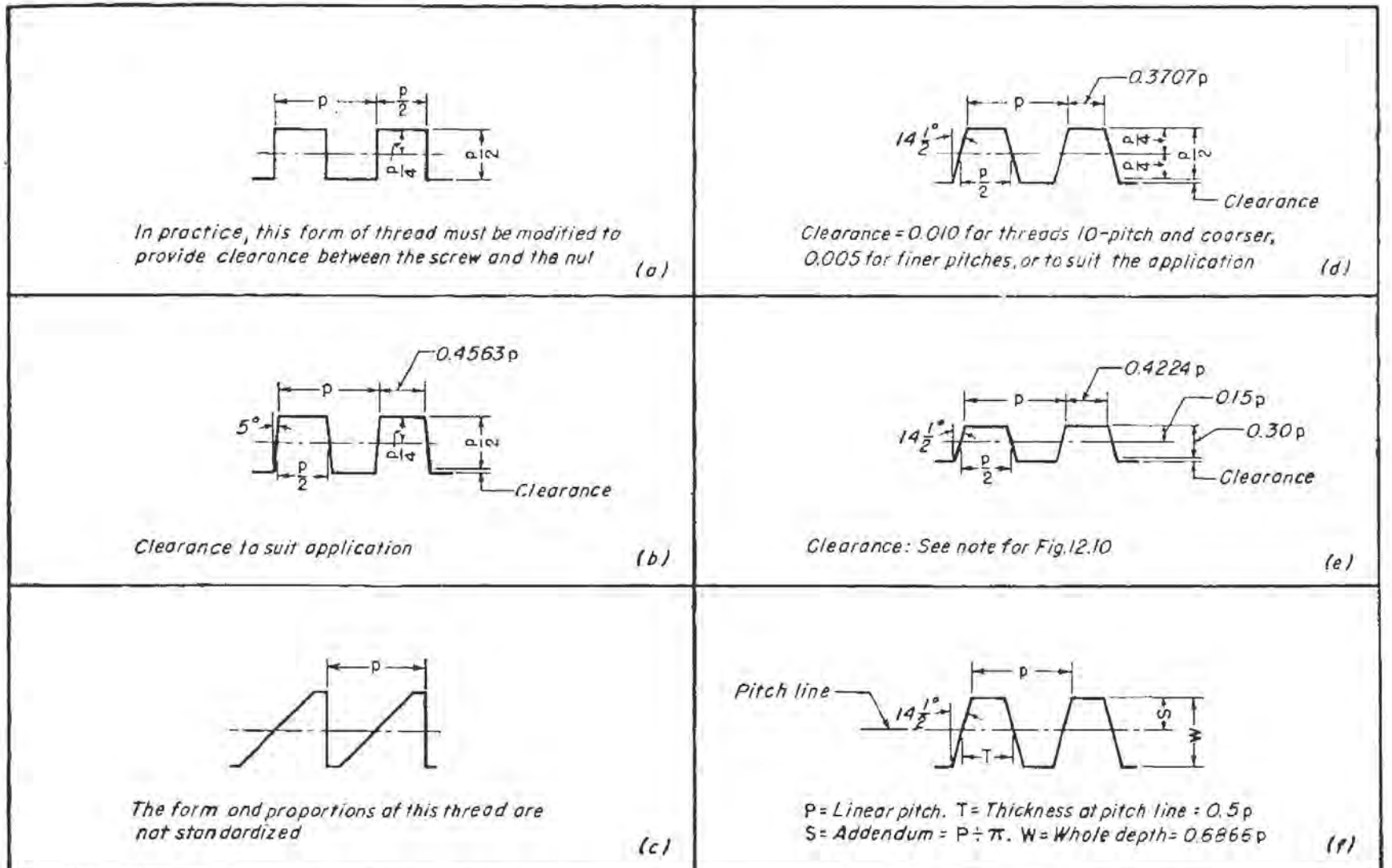


Fig. 12.2 (*a*) Square thread; (*b*) Modified square thread; (*c*) Buttress thread; (*d*) Acme thread; (*e*) 29-deg stub thread; (*f*) Worm thread.

inclusive, are used for translating screws; that is, for screws which are employed to transmit power and motion.

Thread Terms

The most important terms relating to the American National Standard form of thread, and to other threads in general, are illustrated in Fig. 12.3. They are defined as follows:

Major diameter: The largest diameter of a screw or threaded hole.

Minor diameter: The smallest diameter of a screw or threaded hole.

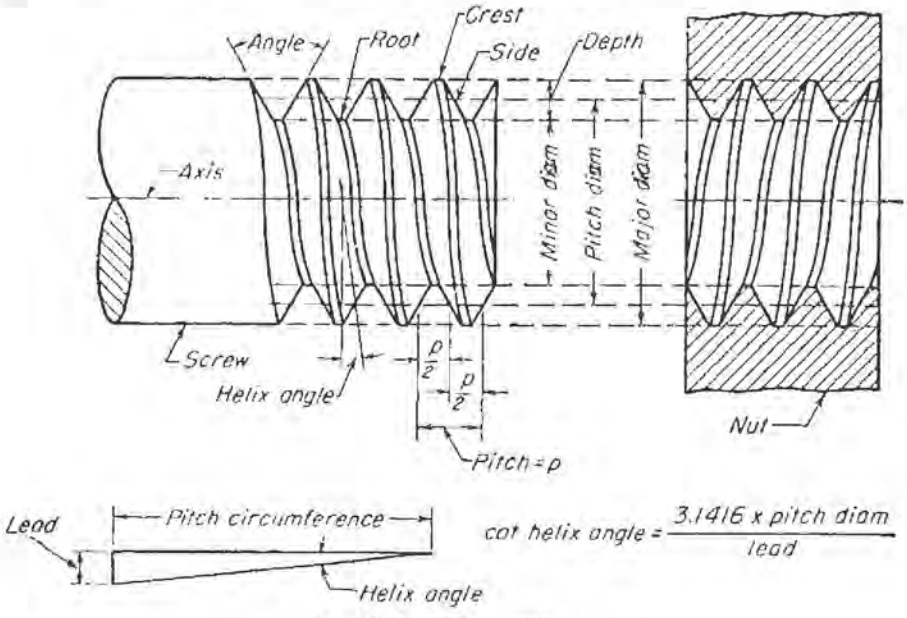


Fig. 12.3 Thread terms.

Pitch diameter: On a straight screw thread, the diameter of an imaginary cylinder whose surface would pass through the threads at such points as to make equal the width of the threads and the width of the spaces cut by the cylinder.

Angle of thread: The angle included between the sides of a thread measured in an axial plane.

Helix angle: The angle made by the helix of the thread at the pitch diameter with a plane perpendicular to the axis.

Crest: The top surface joining the two sides of a thread.

Root: The bottom surface joining the sides of two adjacent threads.

Side: The surface that connects the crest and root of a thread.

Axis: The longitudinal center line of a screw or threaded hole.

Depth: The radial distance from the crest to the root of a thread.

Single and multiple threads: A single thread, or single-start thread, has one ridge formed in the surface of a screw or threaded hole; and a multiple thread, or multiple-start thread, has two or more ridges, as shown in Fig. 12.4.

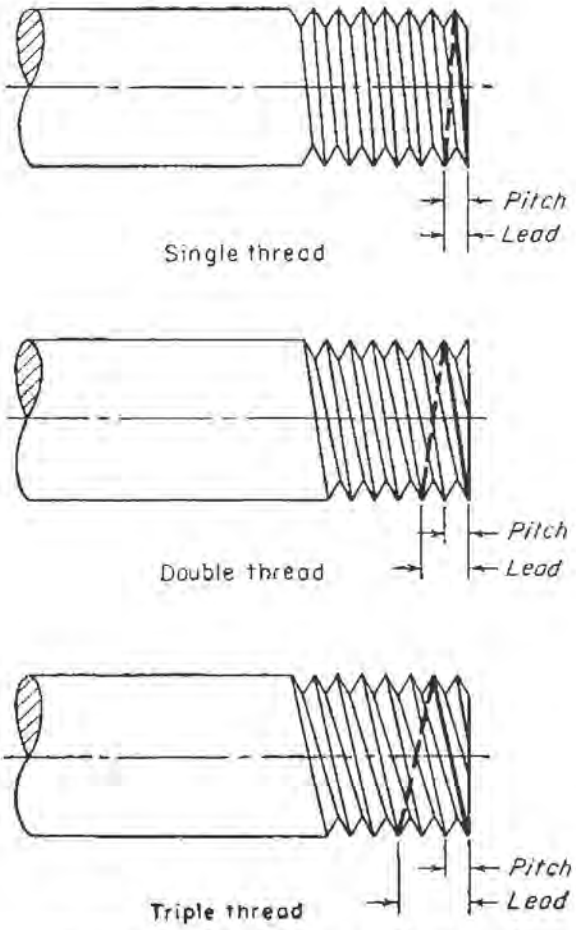


Fig. 12.4 Single and multiple threads.

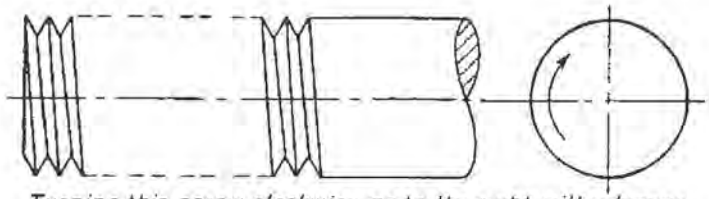
Pitch: The distance from a point on one thread to the corresponding point on the next thread measured parallel to the axis of the screw. The pitch, in inches, is

$$\text{Pitch} = p = \frac{1}{\text{number of threads per inch}}$$

Lead: The distance that the thread advances in one turn measured parallel to the axis of the screw. The lead of a single thread equals its pitch; the lead of a double thread is two times the pitch;

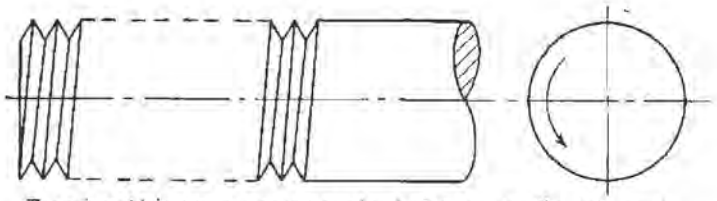
the lead of a triple thread is three times the pitch, etc. These relationships are illustrated in Fig. 12.4.

Right- and left-hand threads: A right-hand thread is one that advances into a nut when it is turned clockwise or to the right, and a left-hand thread is one that advances into a nut when it is turned counterclockwise or to the left, as indicated in Fig. 12.5.



Turning this screw clockwise, or to the right, will advance it into a nut

Right hand thread



Turning this screw counterclockwise, or to the left, will advance it into a nut

Left hand thread

Fig. 12.5 Right- and left-hand threads.

American National Standard Screw Threads

A standard screw thread is one in which (*a*) the form of thread, (*b*) the diameter of the screw, and (*c*) the pitch or number of threads per inch conform to an adopted standard. The dimensional specifications for American Standard Screw Threads for bolts, nuts, machine screws, and threaded parts cover five series of screw threads and provide four classes of screw-thread fit.

The five series of screw threads that employ the American National form of thread but differ in their diameter-pitch relationships, consist of:

1. American Standard Coarse-thread Series. This series is recommended for general use. It is designated on drawings, etc., by the

symbol NC, and it covers the range of sizes and corresponding pitches listed in Table 9.

2. American Standard Fine-thread Series. This series is recommended for use where conditions require a fine thread, as in automotive work. It is designated by the symbol NF, and it covers the range of sizes and pitches listed in Table 10.

3. American Standard 8-pitch Series. All screws and threaded holes in this series have eight threads per inch, and diameters range from 1 to 6 in. inclusive. The symbol 8N is used to designate this series on drawings, etc.

4. American Standard 12-pitch Series. This series covers a range of sizes from $\frac{1}{2}$ to 6 in., inclusive, and it is designated on drawings by the symbol 12N.

5. American Standard 16-pitch Series. A range of diameters from $\frac{3}{4}$ to 4 in., inclusive, is covered by this series, and it is designated on drawings by the symbol 16N.

When the American Standard form of thread is used with a nonstandard diameter-pitch relationship, it is called a "National Special" thread, and it is designated on drawings, etc. by the symbol NS.

American National Standard Screw-thread Fits

Four classes of screw-thread fit are provided for American National Standard Screw Threads by the application of specific tolerances, or tolerances plus allowances. Allowances are applicable in the case of the screw only to the basic pitch diameter of the thread, which is the same for both internal and external threads of the same size and pitch. Tolerances are applied plus to the internally threaded hole, and minus to the externally threaded screw. Class 1 fit is the loosest, Class 4 is the closest, and Classes 2 and 3 fits are graduated between. Descriptions and recommended uses of these fits are as follows:

1. Class 1 fit. A screw and hole threaded to Class 1 specifications will never produce a close fit because the maximum pitch diameter of the screw is always smaller than basic size by a definite allowance,

and the minimum pitch diameter of the threaded hole is basic in size. Therefore, there will always be play, or looseness, between mating parts made to Class 1 fit.

The Class 1 fit is recommended for screw-thread work where clearance between mating parts is essential for rapid assembly, and where shake or play is not objectionable.

2. Class 2 fit. A screw and hole threaded to Class 2 specifications may vary from a fit with no play, when the pitch diameters of both mating parts are basic in size, to a fit with some play, when the total Class 2 pitch-diameter tolerance has been applied to both parts to produce a minimum screw and a maximum threaded hole.

Class 2 represents a high quality of commercial screw-thread product and is recommended for the great bulk of interchangeable screw-thread work.

3. Class 3 fit. A screw and hole threaded to Class 3 specifications may vary from a fit with no play, when the pitch diameters of both mating parts are basic in size, just as in the Class 2 fit, to a fit with about 70 per cent of the play allowed for the Class 2 fit, when the total Class 3 tolerance has been applied to both parts. It is evident, therefore, that all Class 3 product falls within Class 2 specifications.

Class 3 represents an exceptionally high grade of commercially threaded product, and is recommended only in cases where the high cost of precision tools and the continual checking of tools and product is warranted.

4. Class 4 fit. Screws and holes threaded to Class 4 specifications result in a selective-assembly type of fit. There is actual interference between a maximum screw and a minimum hole because the pitch diameter of the maximum screw is greater than the basic size by a definite allowance, and the minimum threaded hole is basic in size. When the total Class 4 pitch-diameter tolerance has been applied to produce a minimum screw and maximum threaded hole, there will be a very slight amount of play.

Class 4 is intended to meet unusual requirements more exacting than those for which Class 3 is intended. It is a selective fit if assembly by hand is required.

American Standard Acme and Other Translating Threads

Four series of screw threads are included in the American Standard for acme and other translating threads: the general purpose acme, the 29-deg stub, the 60-degree stub, and a modified square thread. These screw threads are intended to cover applications for transmitting power and motion. Their respective forms are illustrated in Figs. 12.2*d*, 12.2*e*, 12.1*f*, and 12.2*b*.

American Standard Pipe Threads

American National Standard pipe threads cover both taper and straight pipe threads that are produced in a number of series for various applications. Among them are:

1. American National Standard taper pipe thread, designated by the symbol NPT, that is commonly used in pipe fitting.
2. American National Standard straight pipe thread, designated by the symbol NPSC, which is used in pipe couplings.

Other series cover taper pipe threads that are used for Dryseal joints and railing fittings; and straight pipe threads for grease-cup fittings, mechanical joints, lock nuts and lock-nut pipe threads, and hose couplings and fittings. These are all designated by symbols, similar to those above, that begin with the letters NP.

American National Standard Screw-thread Symbols

Symbols that are used to specify American National Standard screw threads consist of numbers and letters which have significance according to their positions in the symbol. Thus, parts of the symbol $\frac{5}{8}$-11NC-2LH have meaning as follows:

$\frac{5}{8}$	The major diameter of the screw in inches.
11	The number of threads per inch.
NC	The form and series of screw thread.
2	The class of fit.
LH	Left-hand thread. If no symbol is in this position, the thread is assumed to be right-hand.

Methods of Measuring Screw Threads

A number of methods may be used to measure screw threads. The method that is employed in any case depends on the accuracy that is required and on whether a single element of the thread, or several elements in combination are to be checked. The principal tools and methods that are employed are:

1. Scale or gage measurement of the pitch.
2. Screw-thread micrometer caliper.
3. Plug, ring, and snap types of limit gage.
4. Projection comparator.
5. Toolmakers microscope.
6. Three-wire system.
7. Lead checker.

Screw-pitch Gage

The pitch, or number of threads per inch, of a screw thread may be determined by measurement with a screw-pitch gage of the type illustrated in Fig. 12.6. The tool consists of a frame or case, a

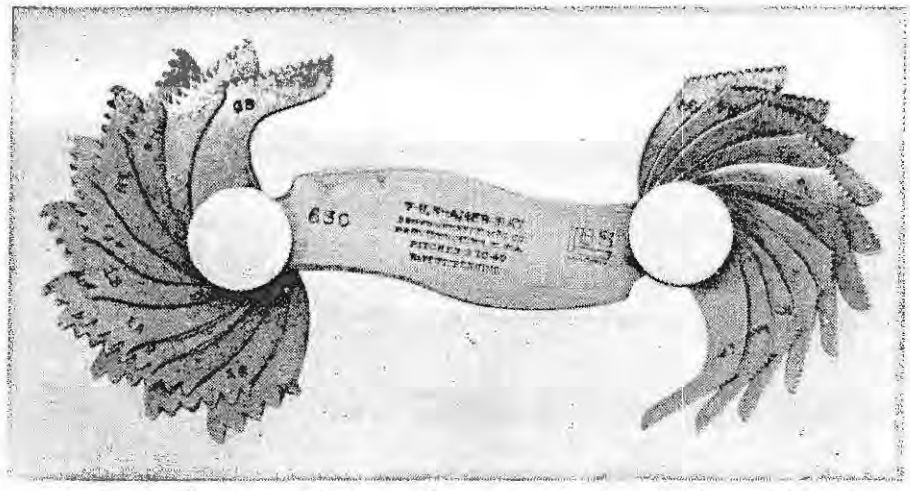


Fig. 12.6 Screw-pitch gage. *Courtesy of Brown & Sharpe Mfg. Co.*

number of notched blades for measuring different pitches, and a means of locking the blades in position for use. Each blade is marked with the number of threads per inch for easy identification, and tools with blades for checking V, American National Standard, Whitworth, or Metric threads are available.

Screw-thread Micrometer Caliper

The screw-thread micrometer caliper, shown in Fig. 12.7, is a micrometer with a spindle and anvil that are designed to measure the pitch diameter of a screw. The spindle is pointed to fit the space between threads, and the anvil is notched to fit over the crest of the opposing thread; both have an allowance so that they will not rest on the root and crest of the thread being measured. When set at

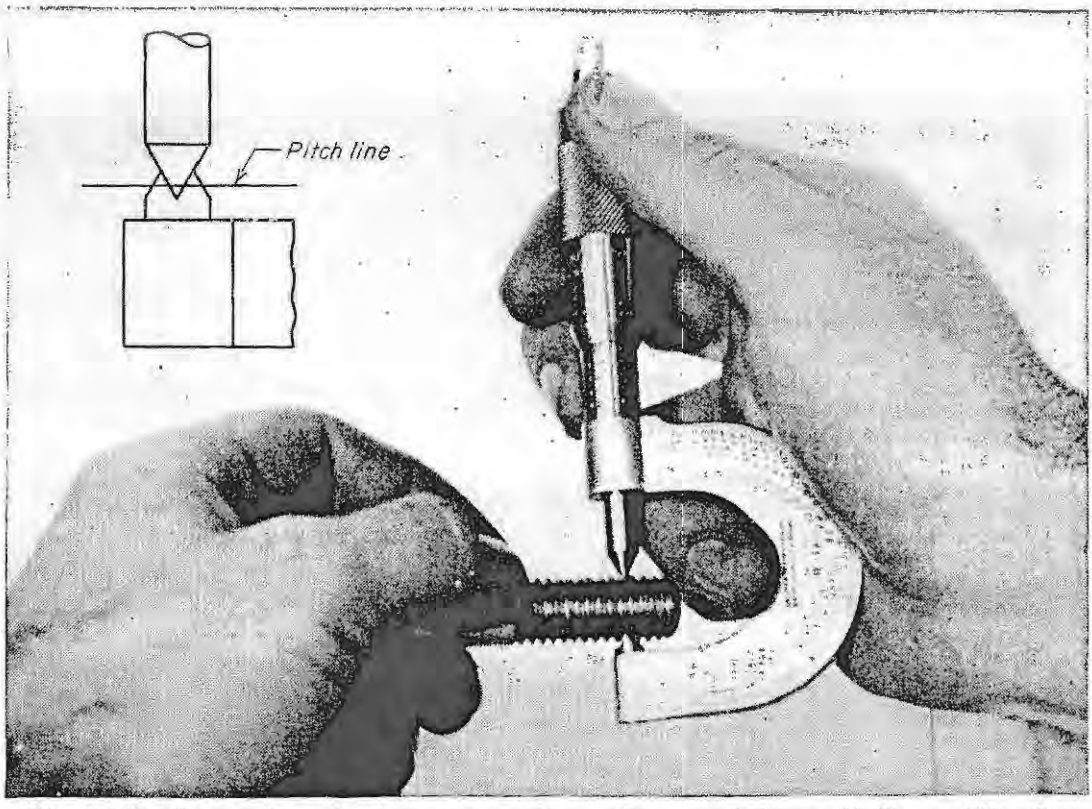


Fig. 12.7 Screw-thread micrometer caliper. *Courtesy of Brown & Sharpe Mfg. Co.*

zero, the pitch lines of the spindle and anvil coincide as shown in the line drawing. When the caliper is opened, the reading represents the distance between the pitch lines, and this equals the pitch diameter of the screw being measured. This tool is made for measuring over a range of 0 to 1 in., and in four models for checking screws having 8 to 13, 14 to 20, 22 to 30, and 32 to 40 threads per inch, respectively. It is available in models for measuring V, American National Standard, and Whitworth threads.

Thread Plug and Ring Gages for Measuring American National Standard Threads

Thread plug and ring gages are used to ensure that American National Standard threads for bolts, nuts, machine screws, and threaded parts shall conform to the limits provided in their specifications as a means of interchangeability in mating parts. This requires the use of "go–not go" gages. A "go" thread plug gage controls the minimum size of a threaded hole, and a "not go" thread plug gage controls its maximum size. Conversely, a "go" thread ring gage controls the maximum size of a screw, and a "not go" thread ring gage controls its minimum size.

A "go" thread gage should check simultaneously as many elements as possible; but a "not go" gage, to be effective, can check one element only. A "not go" thread gage that checks the pitch diameter only is usually sufficient. Gaging practice permits a "not go" thread plug gage to enter a threaded hole and a "not go" thread ring gage to go on a screw, without shake or play, for a distance equal to the length of the respective standard "not go" gages.

Thread plug gages are made in the same American Gage Design Standard taper lock, trilock, and annular designs that are used in the production of plain plug gages. Taper lock design single-end "go", single-end "not go", and double-end "go–not go" thread plug gages, are shown in that order, reading from top to bottom in Fig. 12.8.

Thread ring gages are slotted and provided with adjusting and locking screws for setting them to dimensions required by their applications during manufacturing or resizing operations. "Go–not go" thread ring gages, with a holder, are illustrated in Fig. 12.9. Notice the use of an annular groove to identify the "not go" gage. Thread-setting plug gages are required for setting adjustable thread ring gages and adjustable thread snap gages to size. The minor diameter of a thread ring gage may be checked with a plain plug gage.

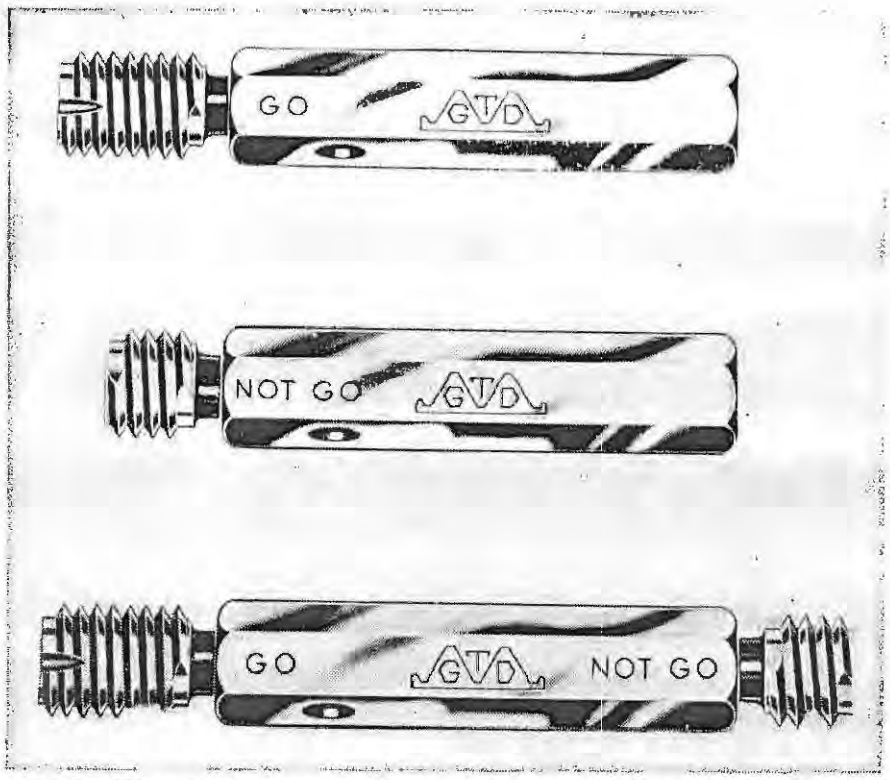


Fig. 12.8 Thread plug gages. *Courtesy of Greenfield Tap and Die Corporation.*

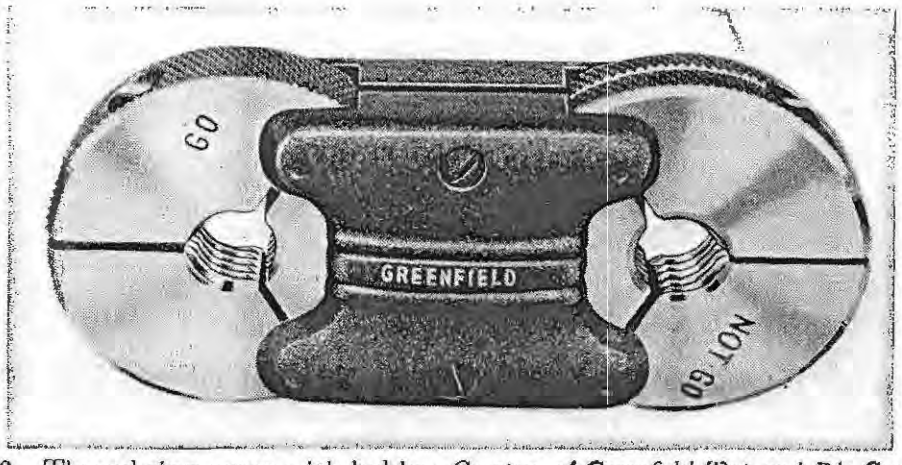


Fig. 12.9 Thread ring gages with holder. *Courtesy of Greenfield Tap and Die Corporation.*

Taper Pipe Thread Plug and Ring Gages

An American National Standard taper pipe thread plug gage is illustrated in Fig. 12.10. Tolerance limits of a threaded hole are checked by the gaging notch shown in the illustration. For a threaded hole to pass inspection, the gage should enter the hole for such a distance that the shoulder of the gaging notch is one turn short of, to one turn beyond the end of the hole.

An American National Standard pipe thread ring gage is shown in Fig. 12.11. Tolerance limits of a threaded pipe are checked with

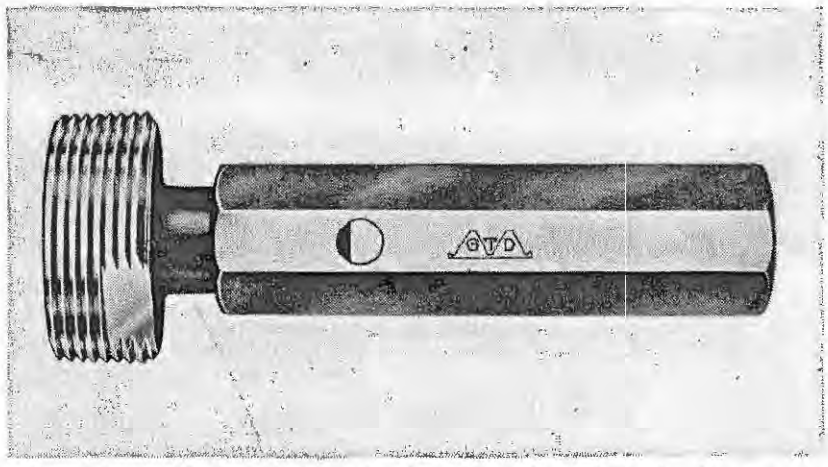


Fig. 12.10 American National Standard taper pipe thread plug gage. *Courtesy of Greenfield Tap and Die Corporation.*

reference to the end surface of the gage at the small end of the taper. The gage should go on the pipe so that its reference surface lies between one turn beyond, to one turn short of the end of the pipe.

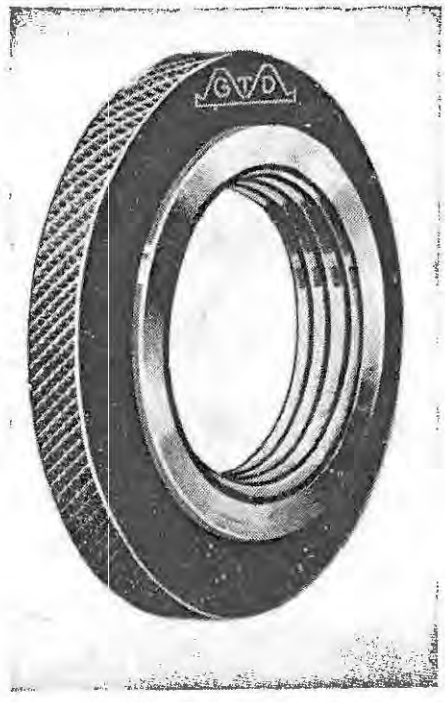


Fig. 12.11 American National Standard taper pipe thread ring gage. *Courtesy of Greenfield Tap and Die Corporation.*

Thread Limit Snap Gages

A roll thread limit snap gage is illustrated in Fig. 12.12. This type of gage, used to inspect external threads, is fast in operation; and the gaging rolls have a large wear area and long life because they are free to rotate on the mounting pins during the inspection operation. The outer or "go" rolls have several gaging ridges to check all thread elements collectively; and the inner or "not go" rolls have only two ridges, used for checking minimum pitch diameters. These gages are made in two general types, as illustrated in Fig. 12.13. The closed-end type at *A*, *B*, and *D* is

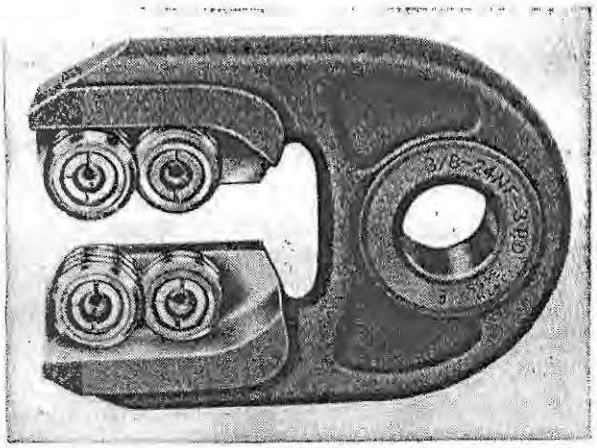


Fig. 12.12 Roll thread limit snap gage. *Courtesy of Greenfield Tap and Die Corporation.*

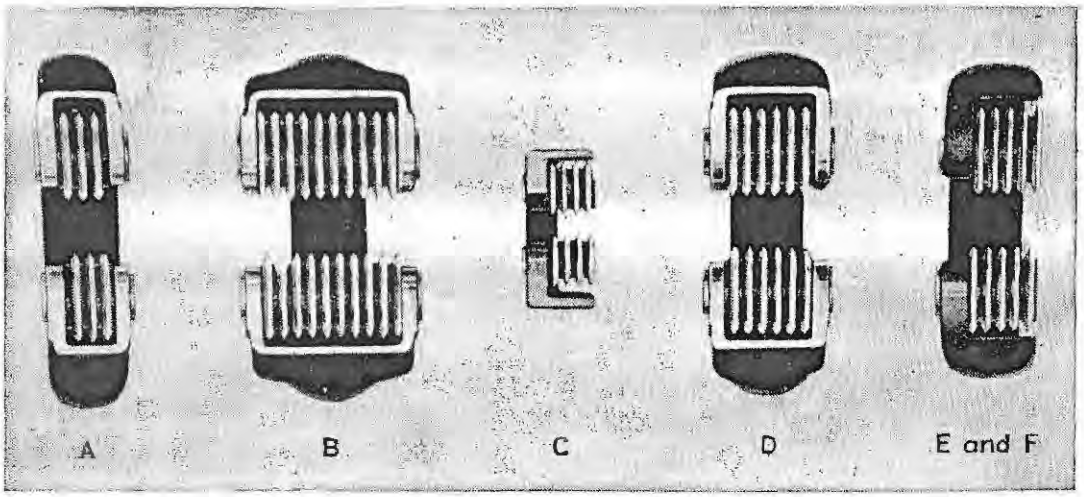


Fig. 12.13 Roll-thread types of gage showing gage rolls supported at both ends, and at one end only. *Courtesy of Greenfield Tap and Die Corporation.*

for general work; and the open-end type at *C*, and *E* and *F* is for use where the thread runs up close to the shoulder.

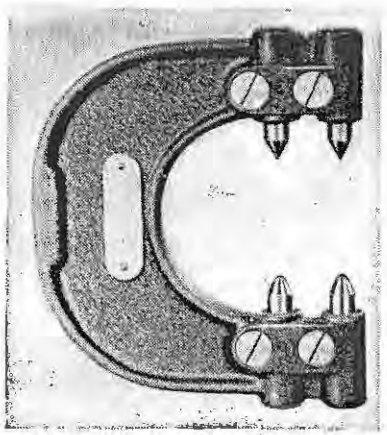


Fig. 12.14 Anvil-type thread limit snap gage. *Courtesy of Greenfield Tap and Die Corporation.*

A gage-pin-type thread limit snap gage is illustrated in Fig. 12.14. The upper pins are pointed to fit in the space between adjacent threads, and the lower pins are grooved to fit over the crest of the opposing thread. This gage is an excellent tool for checking pitch diameters because it checks this element independently of any lead error.

Measuring Screw Threads with an Optical Comparator[1]

The bench comparator, illustrated in Fig. 12.15, is a small optical-projection machine that may be used for the rapid, accurate inspection of screw threads and other irregular profiles. This machine is available in three different table combinations: (*a*) a 12-in. fixed table; (*b*) a 14-in. plain table that may be compounded 15 deg either side of center for inspecting objects with helices; and (*c*) a 16-in. table, that may be compounded, which is equipped for making lateral measurements up to 2 in. with a micrometer or with gage blocks. The third of these models is the one shown in Fig. 12.15.

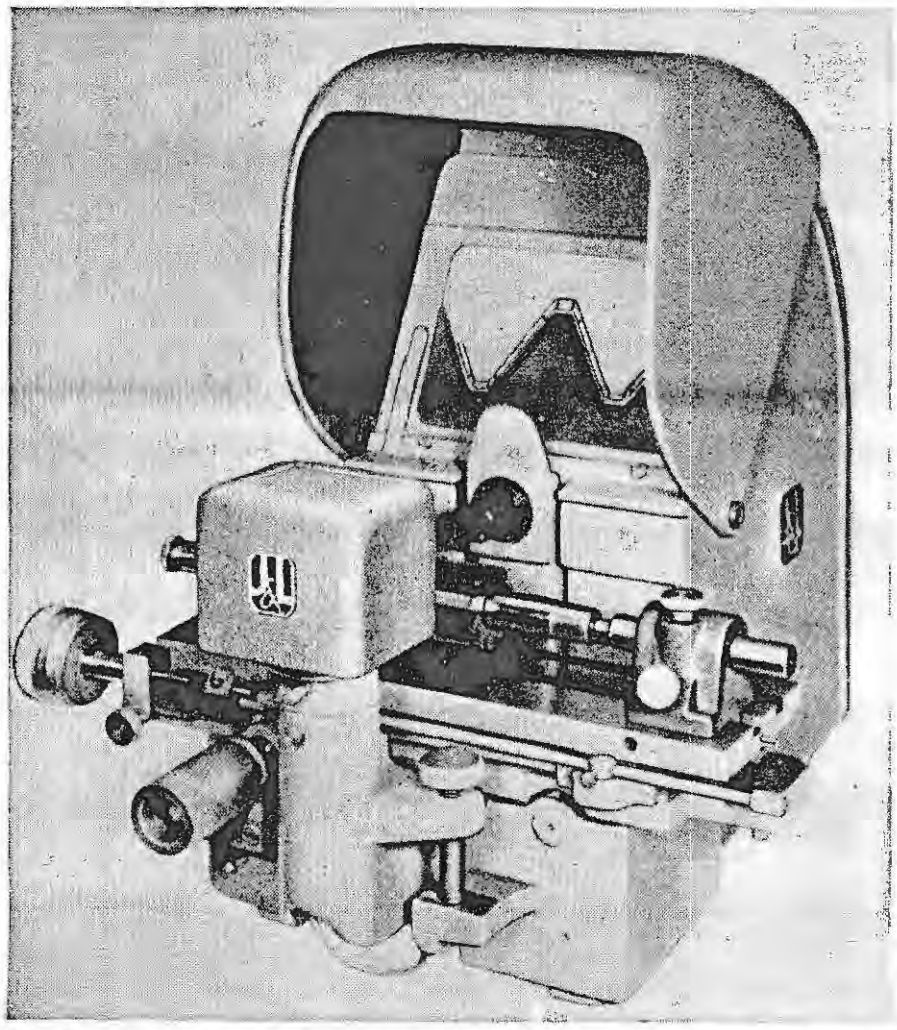


Fig. 12.15 Bench-type optical comparator. *Courtesy of Jones & Lamson Machine Company.*

[1] A general description of optical comparators is given in Chap. 10.

Equipment for measuring screws in large quantities on this machine consists of: a universal staging fixture for holding the work while it is inspected, master gages, and thread-tolerance charts like that shown in Fig. 12.16. The universal staging fixture will hold any screw, with a given form of thread that is from ½ to 1⅜ in. in

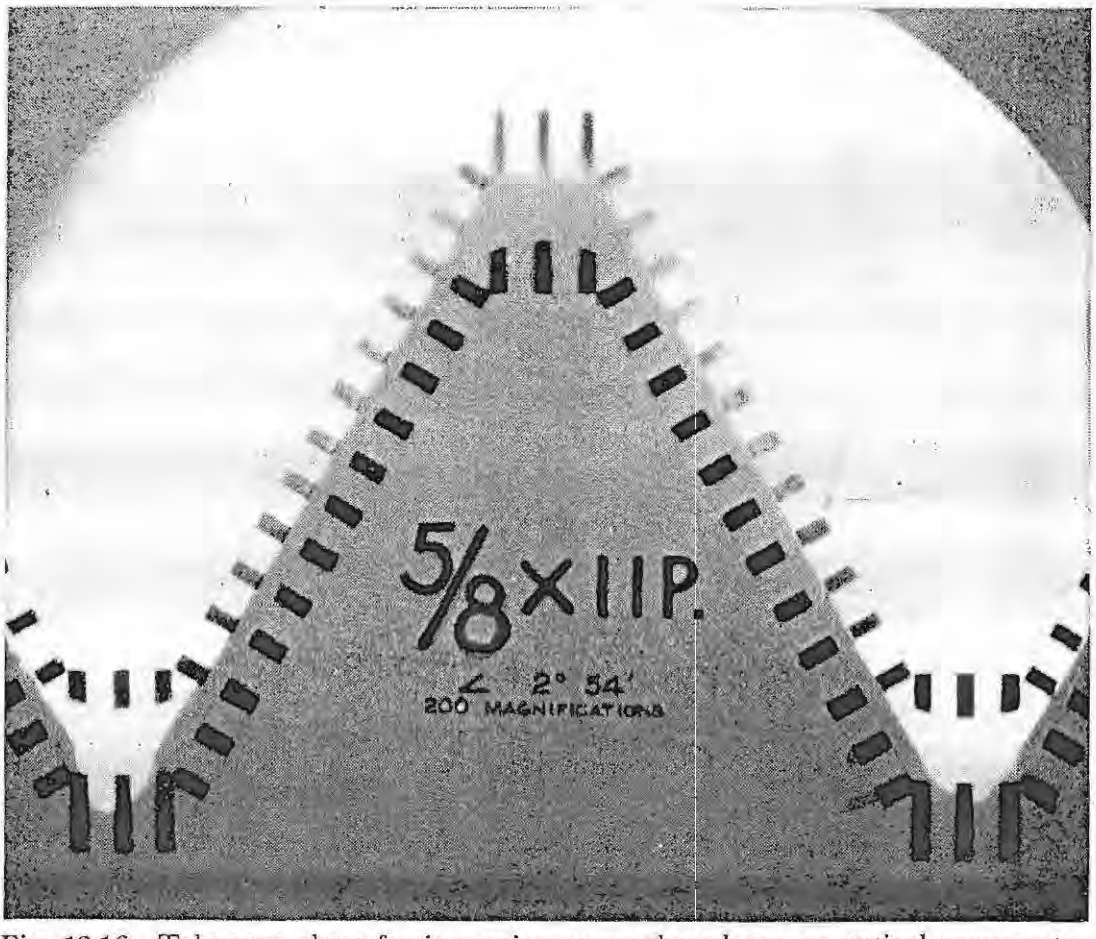


Fig. 12.16 Tolerance chart for inspecting screw threads on an optical comparator. *Courtesy of Jones & Lamson Machine Company.*

diameter, from 44 to 6 pitch, and either right- or left-hand. This equipment may be used with any of the machine models to compare the magnified shadow of a screw with its corresponding thread-tolerance chart.

This instrument is set up to inspect screws by placing a master gage on the universal staging fixture, and adjusting the machine so that the shadow of the thread agrees with the outline of the upper tolerance limit on the thread-tolerance chart. This is the condition

illustrated in Fig. 12.16. Then the master gage is removed from the staging fixture and replaced with a screw to be inspected. For the screw to pass inspection, the shadow of the screw being inspected must fall between the tolerance limits on the chart. Vertical displacement of the shadow shows variation in the pitch diameter of the screw, and lateral displacement of the shadow shows variation in the lead. Lead may be measured on the machine with a table having a 2-in. travel by moving the table and work before the lens with the micrometer in order to check the spacing from thread to thread.

Measuring Screw Threads with a Toolmaker Microscope

The toolmaker microscope, illustrated in Fig. 12.17, has features which are designed especially for inspecting screw threads. One of these, shown plainly in this illustration, is the provision for tilting

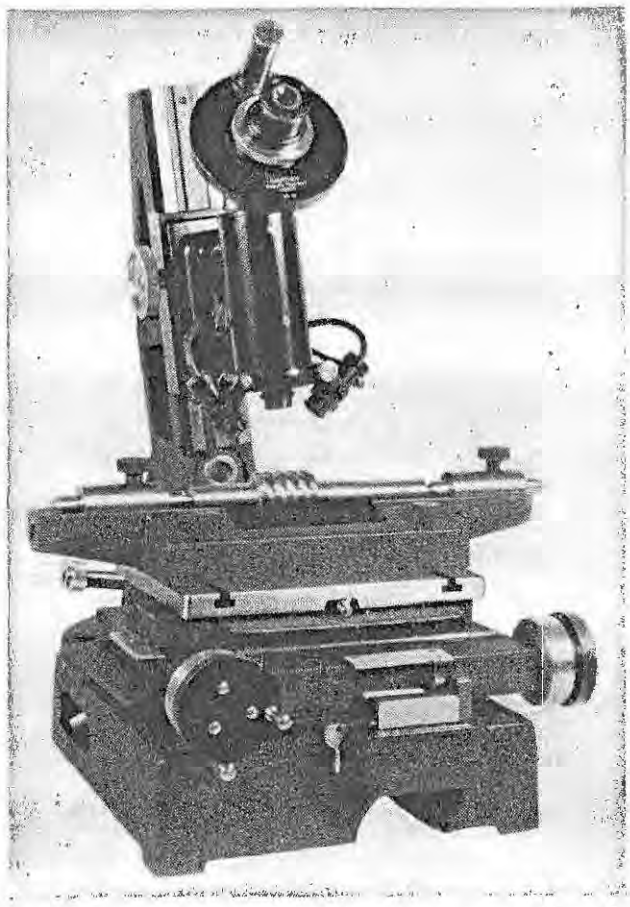


Fig. 12.17 Toolmaker microscope set up to measure a thread. *Courtesy of George Scherr Co., Inc.*

the column of the instrument to the helix angle of the screw being inspected. Although form, angle, depth, lead, and diameter of screw threads may be measured with the standard protractor ocular and table micrometers, their inspection may be performed more rapidly with an interchangeable ocular head which is equipped with a glass slide containing the full series of American National Standard thread profiles from 6 to 80 pitch. The thread profile appears superimposed on the thread image, when looking into the ocular, and any deviation of the thread from standard may be observed readily. Thread lead may be checked by placing a suitable gage block between the micrometer spindle and the anvil of the longitudinal table movement.

Fig. 12.18 Pitch-diameter gage. *Courtesy of Federal Products Corporation.*

Measuring Screw Threads with Dial Indicator Gages

A dial indicator pitch-diameter gage is illustrated in Fig. 12.18. This instrument inspects the pitch diameter of screws by means of ribbed rollers and a dial indicator. The upper roller, with a single annular rib that fits in the space between two adjacent threads, is the sensitive contact which transmits motion caused by variations in size to the dial indicator. The lower roller has two annular ribs that fit over the opposed thread, and it is adjustable so that it may be set to receive a screw of any diameter within the capacity of the instrument. The range of pitches from 4½ to 80 is covered by eight sets of roller anvils which are available as extra equipment. The backstop is adjustable to position screws of all sizes within the capacity of the gage.

A gage of similar construction, but with ball anvils, is available

also. This gage simulates measurement of pitch diameter by the three-wire system, a method which will be described later.

A thread lead gage that inspects the lead of screw threads by the use of conical contact points and a dial indicator is illustrated in Fig. 12.19. The left-hand point is the reference contact, and the right-hand point is the sensitive contact that transmits motion caused by variation in lead to the dial indicator. The points are set for length by inserting them in proper holes and adjusting the ref-

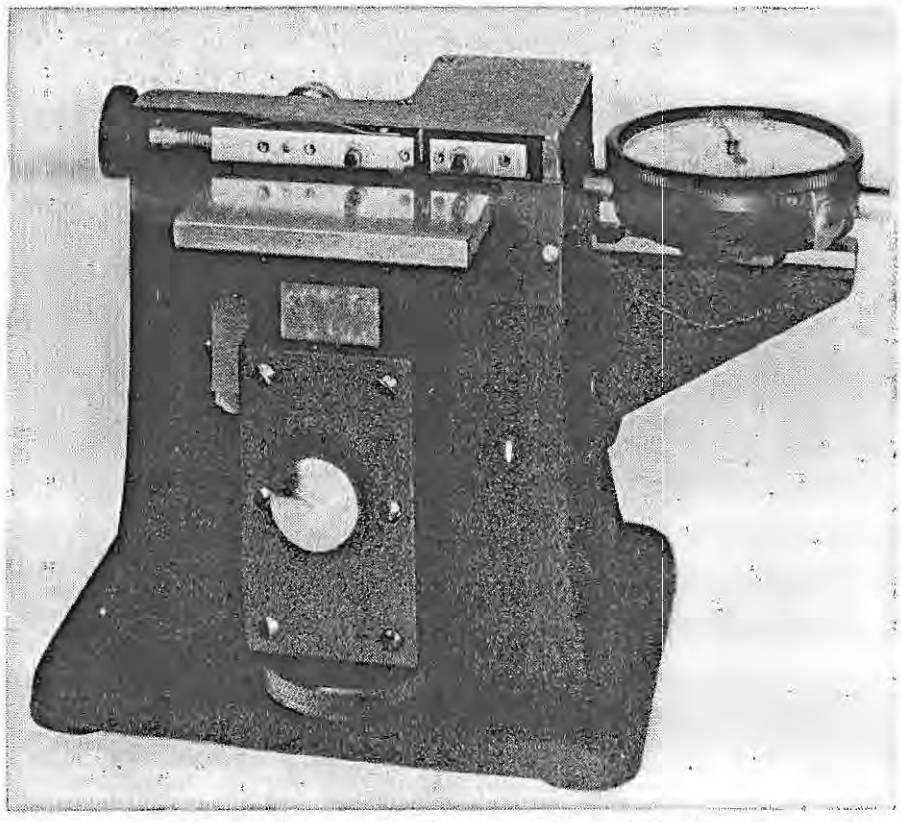


Fig. 12.19 Thread lead gage. *Courtesy of Federal Products Corporation.*

erence-point support to the required size. The worktable may be adjusted vertically to support the center of the workpiece in line with the center of the contact points.

Three-wire System of Measuring Pitch Diameters

The *pitch diameter* of a straight screw thread is the diameter of an imaginary cylinder whose surface will pass through the thread at such points that the widths of the threads and thread spaces, where the surface of the cylinder cuts them, will be equal. This dimension

is important in the production and inspection of screw threads because tolerances, or allowances and tolerances, are applied to their basic pitch diameters to produce different classes of fit.

The three-wire system is the method that is recommended for accurate measurements of screw threads. In applying this method, three wires of equal diameter are placed in the space between threads, as shown in Fig. 12.20, and the distance over the wires is measured with a micrometer or other suitable measuring instrument. The wires should be hard to resist wear, round and straight

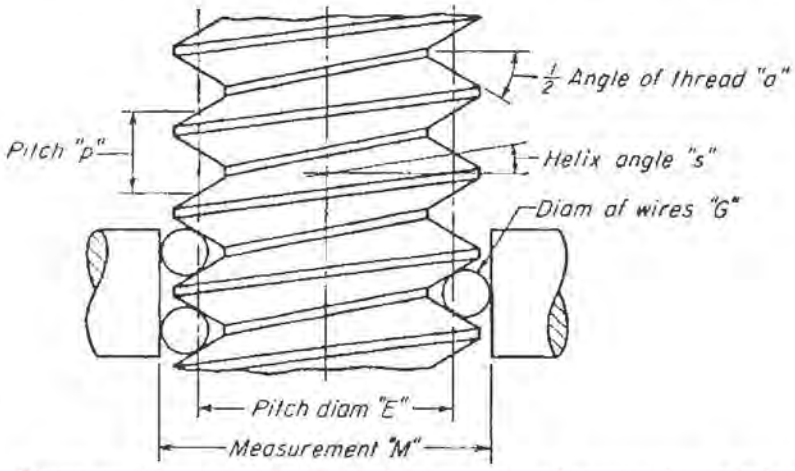


Fig. 12.20 Diagram illustrating three-wire method of measuring pitch diameters of screw threads.

to 0.00002 in., accurate in diameter to 0.00003 in., and within 0.0001 in. of the best size for any given pitch. Measurements are made under standard conditions of 1 lb for pitches finer than 20 threads per inch, and 2½ lb for 20 threads per inch and coarser.

Best-size wires are wires that touch the sides of the thread at the pitch diameter. They are recommended for use because errors in the angle of the thread will not affect the pitch-diameter measurements. Other sizes of wires, however, may be used if necessary. For example, wires having diameters of not less than 0.56 × pitch, nor over 0.90 × pitch, may be used to measure V and American National Standard threads. The diameter of best-size wires may be computed by applying the following formulas:

1. For any angle of thread

$$G = \frac{\sec a}{2n}$$

where G = diameter of best-size wire.
a = one half of angle of thread.
n = number of threads per inch.

2. For V, American National Standard, and other 60-deg threads

$$G = \frac{0.5773}{n}$$

3. For Whitworth 55-deg threads

$$G = \frac{0.5637}{n}$$

4. For Acme and Worm 29-deg threads

$$G = \frac{0.5165}{n}$$

The pitch-diameter measurement over wires may be computed by application of the following formulas:

1. For symmetrical threads using any wires that will fit in the threads

$$E = M + \frac{\cot a}{2n} - G(1 + \csc a) - \frac{G(\tan s)^2 \cos a \cot a}{2}$$

where E = pitch diameter.
M = measurement over the wires.
a = one-half of angle of thread.
G = diameter of wires.
n = number of threads per inch.
s = helix angle.
p = pitch.

The last term in this formula is correction for the helix angle. Unless the correction amounts to more than 0.00015 in., the term is omitted, and the formula becomes

$$E = M + \frac{\cot a}{2n} - G(1 + \csc a)$$

2. For V and American National Standard 60-deg threads, this formula reduces to

$$E = M - (3G - 0.86602\,p) \text{ or } E = M - C$$

where $C = (3G - 0.86602\,p)$ = best wire constant

3. For Whitworth 55-deg threads:

$$E = M - (3.1657\,G - 0.96049\,p) \text{ or } E = M - C$$

4. For Acme and Worm 29-deg threads

$$E = M - (4.9939\,G - 1.93334\,p) \text{ or } E = M - C$$

A set of best-size wires for measuring screw threads is illustrated in Fig. 12.21. In practice, it is not necessary to compute the constant

Fig. 12.21 A set of best-size wires for measuring screw threads. *Courtesy of The Van Keuren Co.*

C in the formulas above because its value, for any given pitch, is given on the label of the container for the best-size wires for that pitch.

An application of best-size wires for measuring straight-thread plug gaging members of taper lock design with a Supermicrometer is illustrated in Fig. 12.22; and the best-size wires being used with a

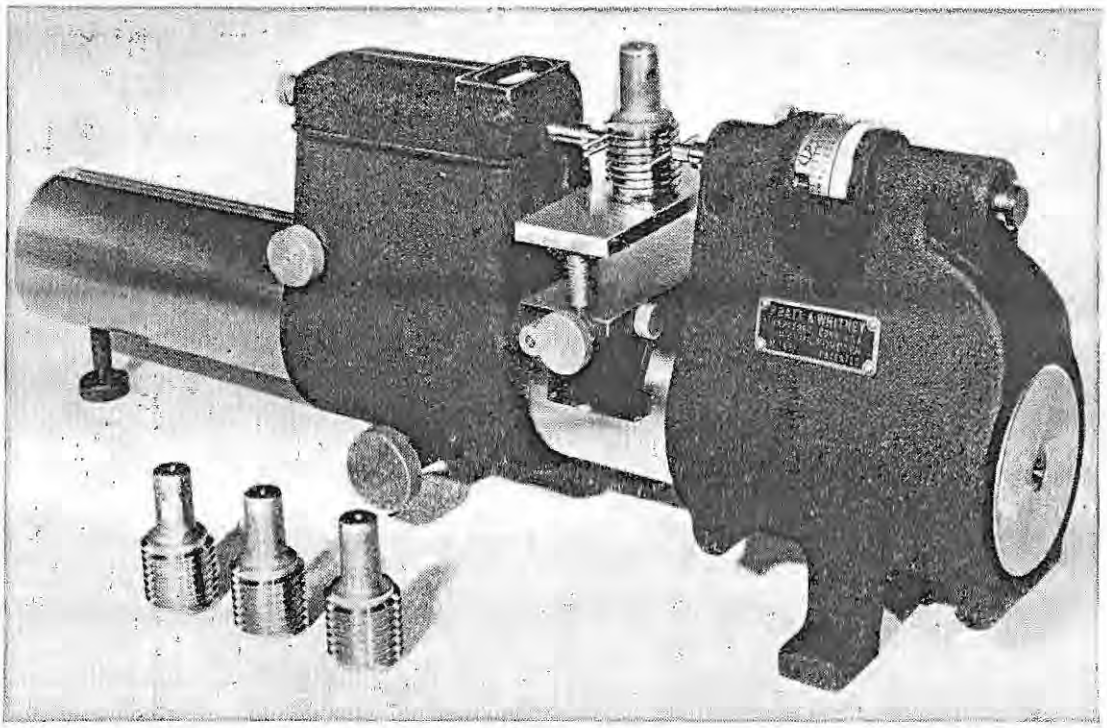


Fig. 12.22 Measuring thread plug gaging members, taper lock design, with best-size wires and a supermicrometer. *Courtesy of Pratt & Whitney; Photo from Pratt & Whitney Division, Niles-Bement-Pond Co.*

sine-bar fixture to measure a taper plug gage of taper lock design on a Visual Gage is shown in Fig. 12.23.

A Measure Master machine which is used to measure screw threads by the wire method, but with only two wires instead of the cutomary three, is illustrated in Fig. 12.24. The thread-measuring wires are suspended from above. A large disk under a magnifier and a pressure anvil permit accurate readings to 0.0001 in.

Detail dimensions of screw-thread elements, allowances, tolerances, limits for different classes of fit, and dimensions of screw-thread gages have not been given in this chapter. Information of

that nature should be obtained from handbooks or from the following publications of The American Society of Mechanical Engineers:

B1.1-1949, "Unified and American Screw Threads for Screws, Bolts, Nuts, and Other Threaded Parts."

B1.2-1951, "Screw-thread Gages and Gaging."

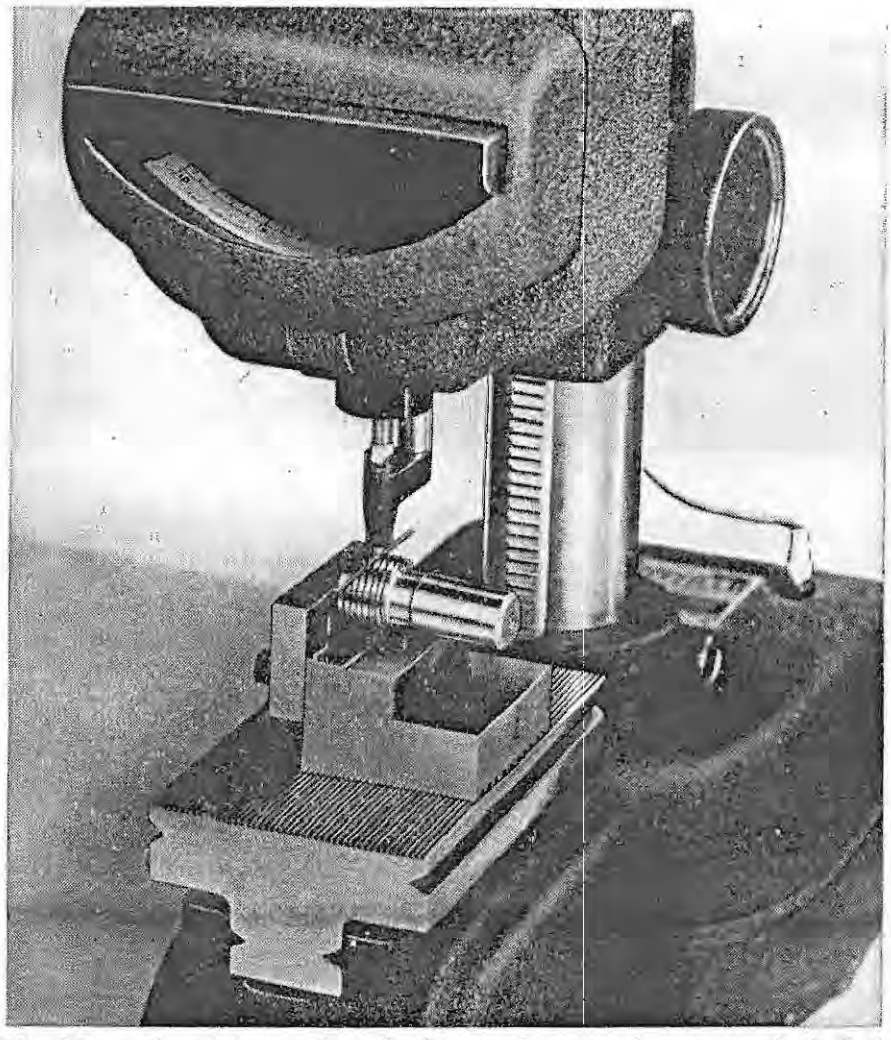


Fig. 12.23 Measuring a taper thread plug gaging member, taper lock design, with best-size wires, a fixture, and a visual gage. *Courtesy of The Sheffield Corporation.*

B1.5-1945, "Acme Threads" (American War Standard).

Definitions in this chapter have been extracted from "Unified and American Standard Screw Threads for Screws, Bolts, Nuts, and Other Threaded Parts" (ASA B1.1-1949), with the permission of the publisher, The American Society of Mechanical Engineers, New York.

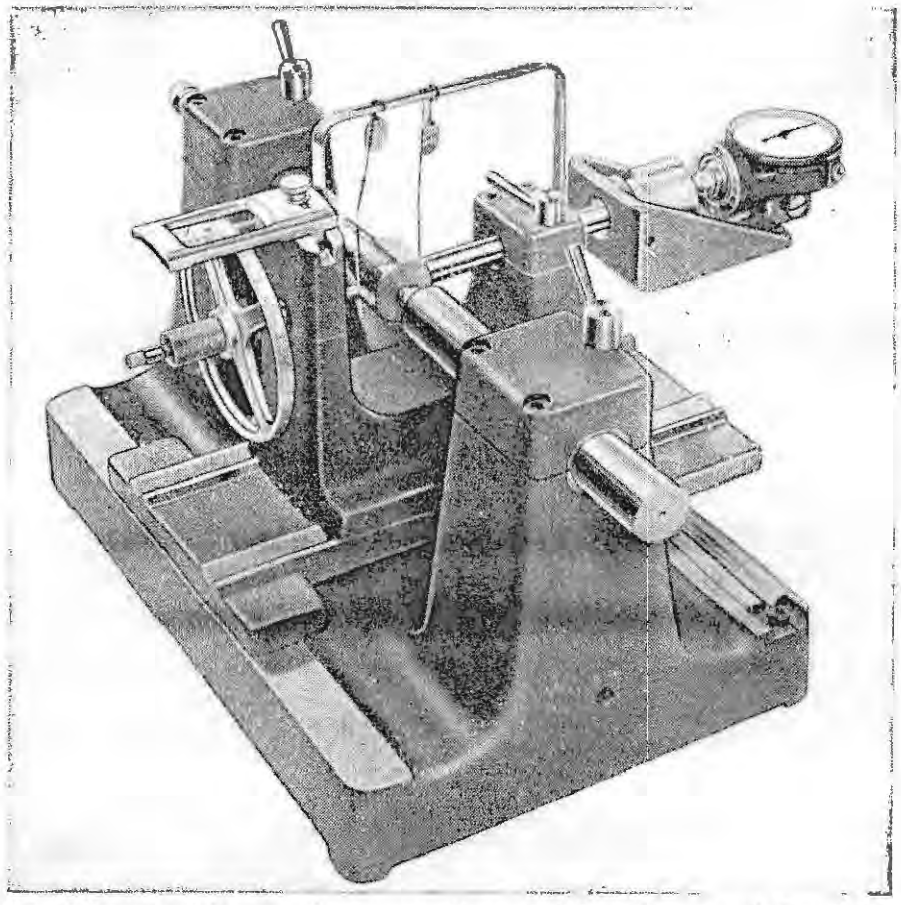


Fig. 12.24 Measure Master wire measuring machine. *Courtesy of Greenfield Tap and Die Corporation.*

QUESTIONS

1. Name the form of screw thread that is used for bolts, nuts, etc., in the United States.

2. Name the form of screw thread that is used for bolts, nuts, etc., in Great Britain.

3. Name the form of screw thread that has been adopted to secure interchangeability in the threaded products of the United Kingdom, Canada, and the United States.

4. Name four screw-thread forms that are used for translating screws.

5. Define the following terms relating to the American National Standard and other screw threads: (*a*) major diameter, (*b*) minor diameter, (*c*) pitch diameter, (*d*) angle of thread, (*e*) helix angle, (*f*) crest, (*g*) root, (*h*) side, (*i*) axis, (*j*) depth, (*k*) single thread, (*l*) multiple thread, (*m*) pitch, (*n*) lead, (*o*) right-hand thread, (*p*) left-hand thread.

6. Name and describe the method that is recommended as the most accurate for measuring screw threads.

7. Name and describe four other methods of measuring screw threads.

13

GEAR INSPECTION

Gears are wheels that are used to transmit rotary motion, usually at a uniform angular velocity, between shafts which are relatively near each other. Friction gears, consisting of plain cylinders or cones, may be used in transmissions when loads are light and slippage is unimportant. Most machines, however, require positive drives between shafts; and teeth are added to the cylinders and cones to produce toothed gearing. The friction wheels to which teeth are added are called "pitch cylinders" and "cones," and their circumferences are called "pitch circles."

Types of Gears

Four types of toothed gears are in common use: spur gears, bevel gears, helical or "spiral" gears, and worm gears.

Spur gears, illustrated in Fig. 13.1, are used to transmit motion between parallel shafts. Their pitch surfaces are cylinders, and their tooth elements are straight and parallel to the axes of the shafts.

Bevel gears, shown in Fig. 13.2, are used to transmit motion between shafts whose axes intersect. Their pitch surfaces are cones, and their tooth elements are straight lines that converge at the vertex of the cones. The shafts of most bevel gears are at an angle of 90 deg to each other; however, they may be at other angles. *Miter gears* are pairs of bevel gears whose axes intersect at an angle of 90

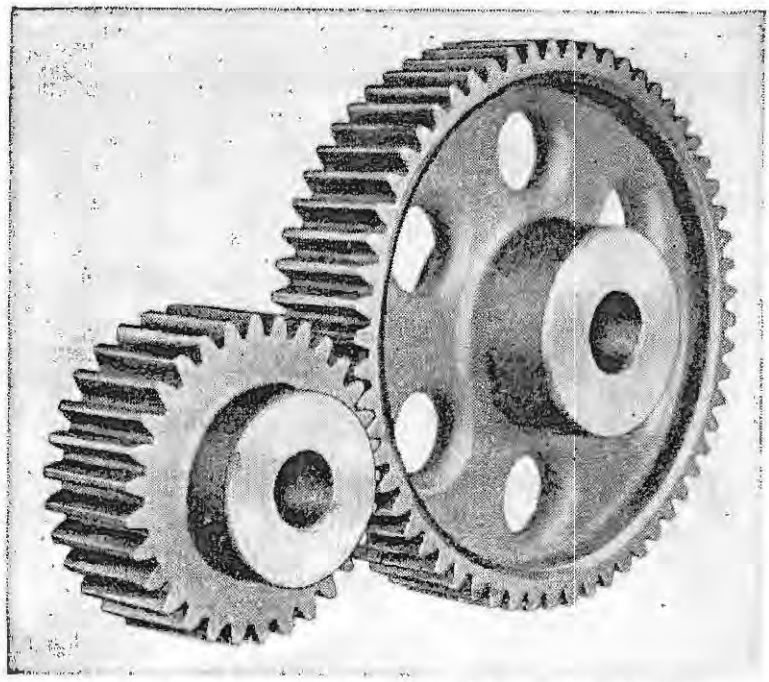


Fig. 13.1 Spur gears. *Courtesy of Boston Gear Works.*

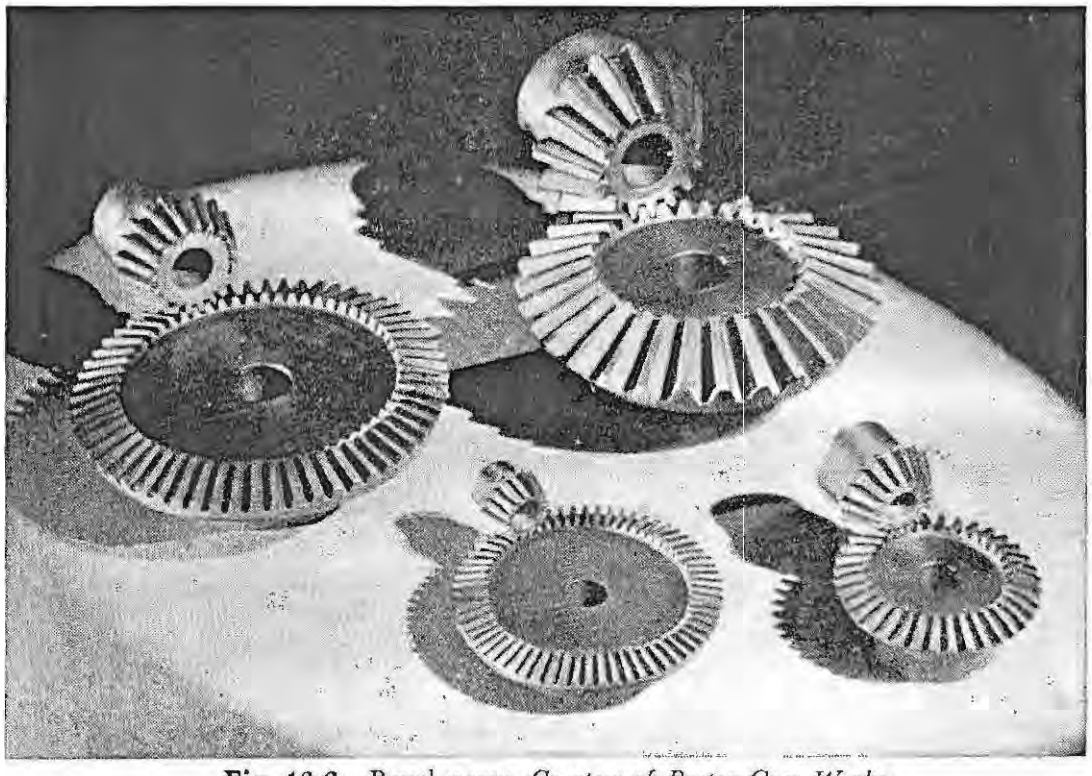


Fig. 13.2 Bevel gears. *Courtesy of Boston Gear Works.*

deg, and that have equal numbers of teeth. *Spiral bevel gears* have curved, instead of straight teeth, and the tooth elements are curved lines that converge at the vertex of the pitch cones.

Fig. 13.3 Helical gears. *Courtesy of Boston Gear Works.*

Helical or "spiral" gears, shown in Fig. 13.3, have cylindrical pitch surfaces the same as spur gears, but their teeth follow a helical course instead of being straight and parallel to the axis. Helical gears may be used to transmit motion between parallel shafts or between nonintersecting, nonparallel shafts at any angle, depending on the hand and helix angles of the teeth. A *herringbone gear* is, essentially, two helical gears having the same helix angles and numbers of teeth, but with opposite hands, that are placed together side-by-side to form a single unit. Herringbone gears are used to transmit motion between parallel shafts.

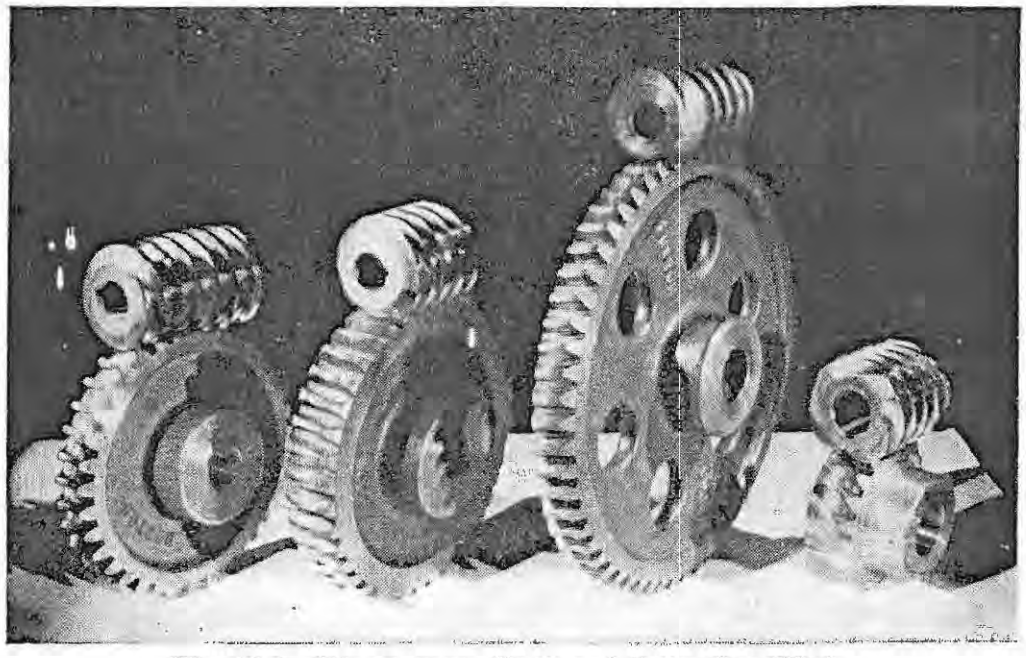


Fig. 13.4 Worm gears. *Courtesy of Boston Gear Works.*

Worm gears, illustrated in Fig. 13.4, are used to transmit motion between nonintersecting shafts at 90 deg to each other when large speed reductions are necessary. A worm-gear drive consists of a driving member, called a "worm," and a driven member, called a "worm gear." Worm gearing is, essentially, helical gearing in which the worm has threads instead of teeth.

Gear Nomenclature

Terms that apply generally to spur and other types of gears are illustrated in Fig. 13.5 and are defined in the following list:

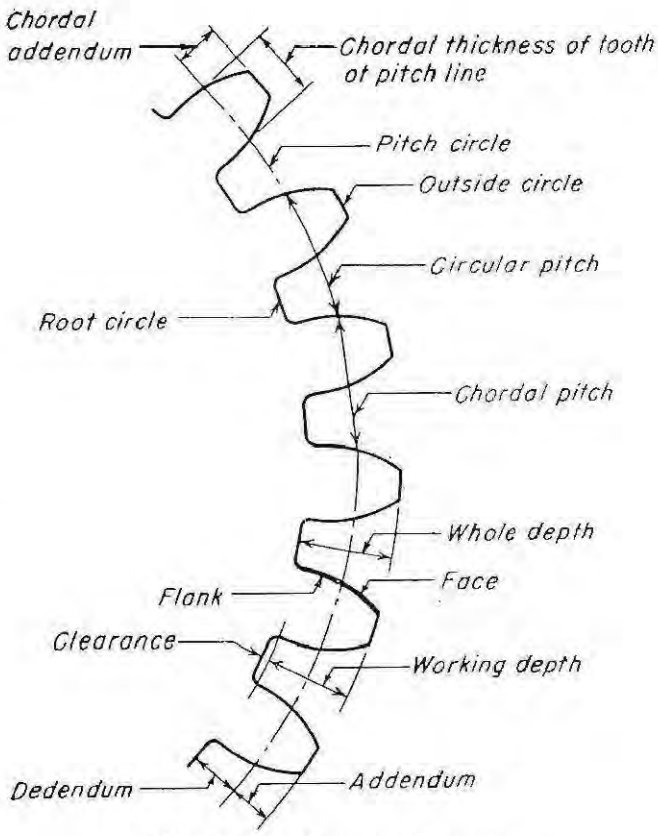


Fig. 13.5 Gear-tooth parts.

Pitch cylinder and pitch cone: The basic cylinders and cones to which teeth are added to form toothed gearing.

Pitch circle: The circumference of a pitch cylinder or pitch cone.

Pitch diameter: The diameter of a pitch circle.

Pitch point: The point where the pitch circles of two gears in mesh with each other intersect their common center line.

Diametral pitch: The number of teeth in a gear for each inch of its

pitch diameter. For example, a 24-tooth gear with an 8-in. pitch diameter has three teeth for each inch of its pitch diameter; therefore, its diametral pitch is 3. Whenever the word pitch is used without a modifier, it is always understood to mean diametral pitch.

Circular pitch: Circular pitch is the distance from any point on one tooth of a gear to the corresponding point on the next tooth measured along the arc of the pitch circle.

Chordal pitch: The distance from any point on one tooth of a gear to the corresponding point on the next tooth measured along the chord of the pitch circle.

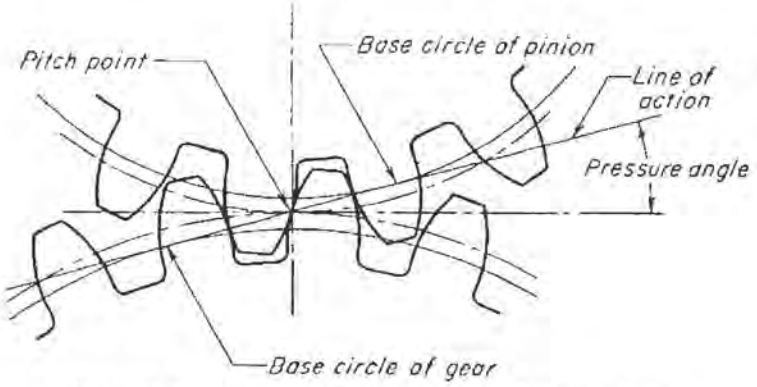


Fig. 13.6 Base circle, etc., of involute gearing.

Chordal thickness: Thickness of a gear tooth measured on the chord of the pitch circle.

Chordal addendum: The radial distance from the center of the chord above to the outside circle measured on the center line of the tooth.

Addendum: The radial distance on a gear tooth between the pitch circle and the outside circle.

Dedendum: The radial distance on a gear tooth between the pitch circle and the root circle.

Whole depth: The sum of the addendum and the dedendum.

Clearance: The radial distance between the top of a gear tooth and the bottom of the tooth space with which it is meshed in the mating gear.

Working depth: The difference between the whole depth and the clearance.

Face: The surface of a gear tooth between the pitch circle and the outside circle.

Flank: The surface of a gear tooth between the pitch circle and the root circle.

Additional terms, illustrated in Fig. 13.6, applying to involute gearing, are:

Base circle: The circle, in involute gearing, from which the form of the gear tooth is generated.

Line of action: A line that is drawn tangent to the base circles of two involute gears which are in mesh with each other. Tooth contact between the gears is maintained along this line as they rotate.

Pressure angle: The angle between the line of action and a line perpendicular to the common center line of a pair of gears at the pitch point.

Systems of Gearing

The form of gear teeth is affected, mainly, by two conditions:

1. The need to transmit rotary motion between shafts at a uniform angular velocity.

2. The need, in many cases, for gears in a train to be interchangeable.

These considerations have lead to the development of two systems of gearing:

1. *Cycloidal system:* In the cycloidal system, the contour of the gear teeth is made up of cycloidal curves. This system is used mainly for cast gearing and in the composite system of gearing, to be described later.

2. *Involute system:* In the involute system, an involute is generated from a base circle that is located inside the pitch circle to form the contour of this tooth.

Two pressure angles are used in American Standard Gear Systems:

1. American Standard 14½-deg full-depth involute system. In this system the pressure angle is 14½ deg, and the full depth equals $2.157/DP$ when DP = the diametral pitch. The basic rack has a straight-sided tooth at 14½ deg to the center line of the tooth.

2. American Standard 20-deg full-depth involute system. The pressure angle is 20 deg, and the full depth equals $2.157/DP$.

3. American Standard 14½-deg composite system. The basic rack in this system has an approximation of cycloidal curves above and below the pitch line.

4. American Standard 20-deg stub-tooth involute system. The full depth of the tooth equals $1.800/DP$.

Handbook formulas and tables may be used to determine dimensions of both gear teeth and gear diameters when they are required.

The principal tests for inspecting gears are measurements of tooth thickness, pitch diameters, eccentricity, tooth spacing, tooth profile, helix angle or lead of helical gears, and a sound test.

Measurement of Gear-tooth Thickness

The chordal thickness at the pitch line, and the chordal addendum of a gear tooth, may be measured with the gear-tooth vernier caliper in the manner illustrated in Fig. 13.7. Dimensions for setting the jaws and tongue of this tool may be computed by means of formulas; or they may be determined for standard addendums, more conveniently, from a table. Both formulas and table are published in machinists' handbooks.

A second method for checking the thickness of teeth at the pitch line consists of measuring over wires, placed in opposing tooth spaces, with a micrometer or other suitable tool. The wires, which are made in sets of two for each diametral pitch, are produced in four series of sizes for measuring external spur and helical gears, internal spur gears and splines, enlarged pinions and involute splines, and for special requirements. Actual measurements over the wires are compared with values that have been computed for perfect gears to determine plus or minus variations from standard sizes. Two tables of values are needed to apply this method: one for use with even-toothed gears because the wires are in diametrically opposed spaces, and the other for use with odd-toothed gears because one wire must be one-half tooth off the center line.[1]

A third method of checking gear-tooth thickness employs gear

[1] Consult The Van Keuren Company's Catalog and Handbook for tables and a full explanation of this method.

measuring blocks that are made in sets of three for each pitch and pressure angle to be checked. Two blocks, shaped like a basic rack tooth, are used in measuring even-toothed gears; and the third block, grooved with a tooth space, is used with one of the tooth-

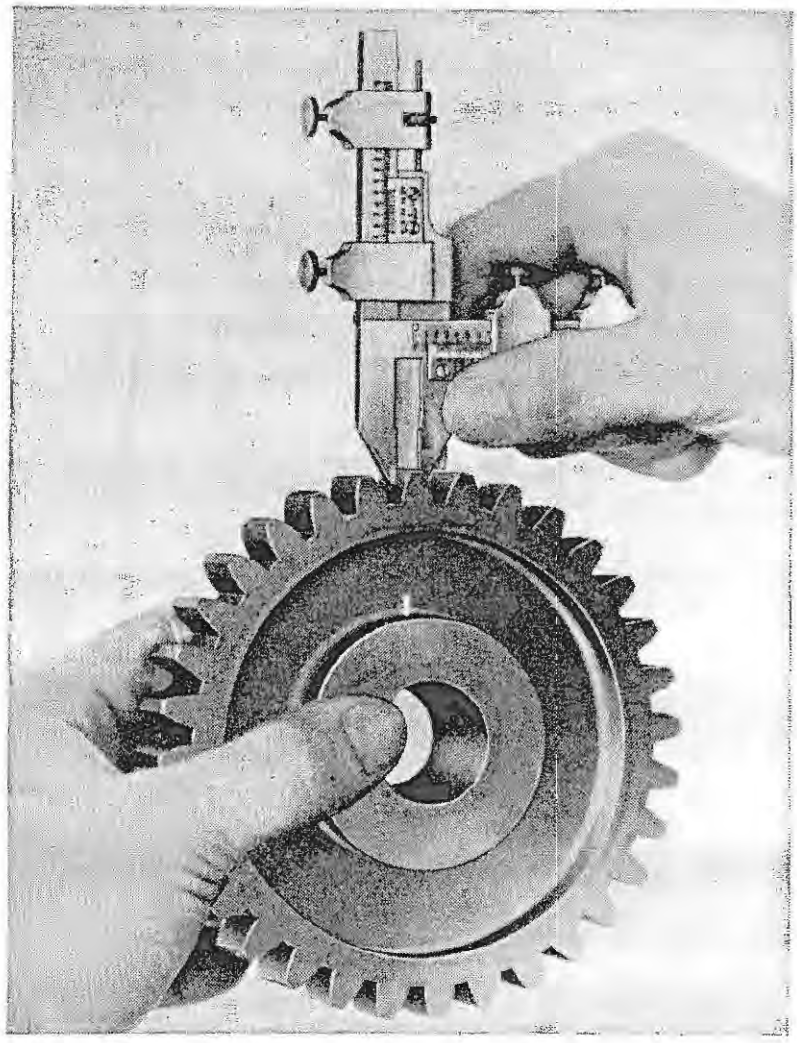


Fig. 13.7 Gear-tooth vernier. *Courtesy of Brown & Sharpe Mfg. Co.*

shaped blocks to measure odd-toothed gears. Measurements over the blocks are made with a micrometer or other suitable tool.

Red Ring Gear Speeder

The National Broach & Machine Co.'s Red Ring Gear Speeder, shown in Fig. 13.8, is used to inspect gears acoustically. The set of gears to be tested is mounted on suitable spindles, as illustrated in Fig. 13.9, and run at varying speeds. The sound chamber, with its

horn, amplifies noise about 50 times. The gear center distance is adjustable and may be set by measuring over the spindles with a micrometer, or by using gage blocks between stop plates. Special machines for testing three spindle sets of gears, and for other special requirements, can be furnished.

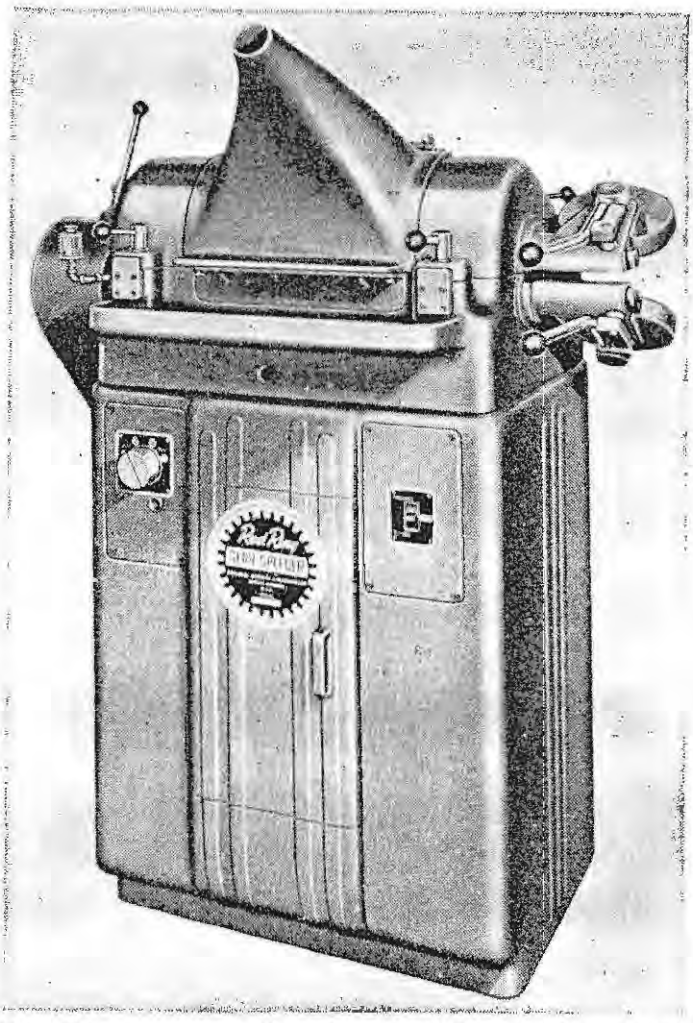


Fig. 13.8 Red Ring gear speeder. *Courtesy of National Broach & Machine Co.*

Red Ring Universal Gear Checker and Lead Comparator

The National Broach & Machine Co.'s Red Ring Universal Gear Checker and Lead Comparator consists of a surface-plate table on a heavy base; headstock and tailstock centers for holding work to be inspected; and fixtures and instruments to measure errors in index, eccentricity, tooth parallelism of spur gages, and helix angle or lead of helical gears. In Fig. 13.10, this tool is shown

set up to test the lead of a helical gear against a slot in a master lead cylinder. The spacing head for this tool, shown in Fig. 13.11, is used to measure index or tooth spacing by comparing the spacing of teeth with an original setting made on two selected adjacent teeth. Any error in spacing is read directly on a 0.0001-in. dial in-

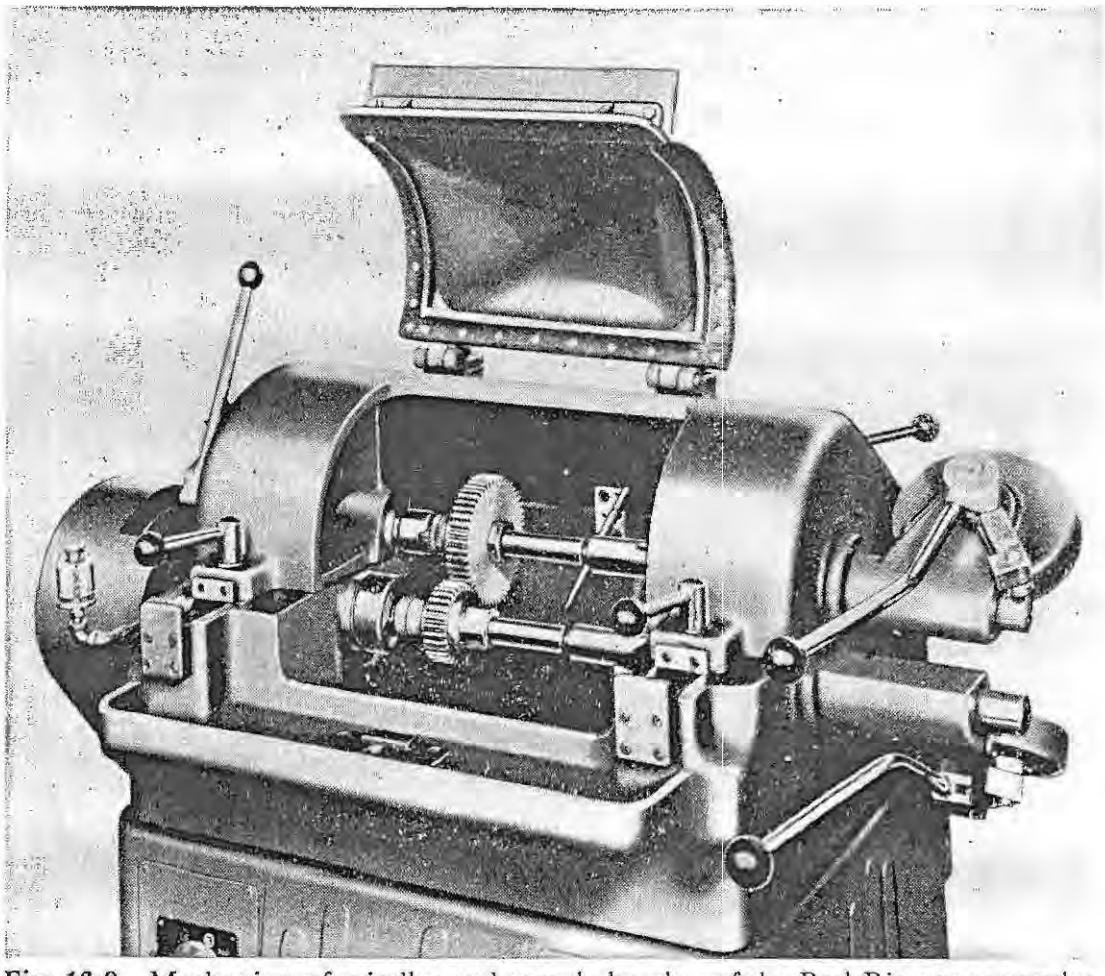


Fig. 13.9 Mechanism of spindles and sound chamber of the Red Ring gear speeder. *Courtesy of National Broach & Machine Co.*

dicator which is actuated by movement of the movable finger with reference to the stop finger.

The angle and eccentricity head (Fig. 13.12) checks helix angle by comparing it with the angle of a rack-tooth nosepiece set to the proper angle by placing gage blocks under the sine-bar buttons. When the rack-tooth nosepiece is moved into contact with the gear teeth, variation in the helix angle is shown on the angle indicator.

In a similar manner, eccentricity is measured on the eccentricity indicator as successive teeth around the gear are tested.

Cone, Spacing, and Taper Inspection Instrument[1]

The Fellows No. 12C Inspection Instrument, shown in Fig. 13.13, may be used to check cone and tooth spacing of gears. The instru-

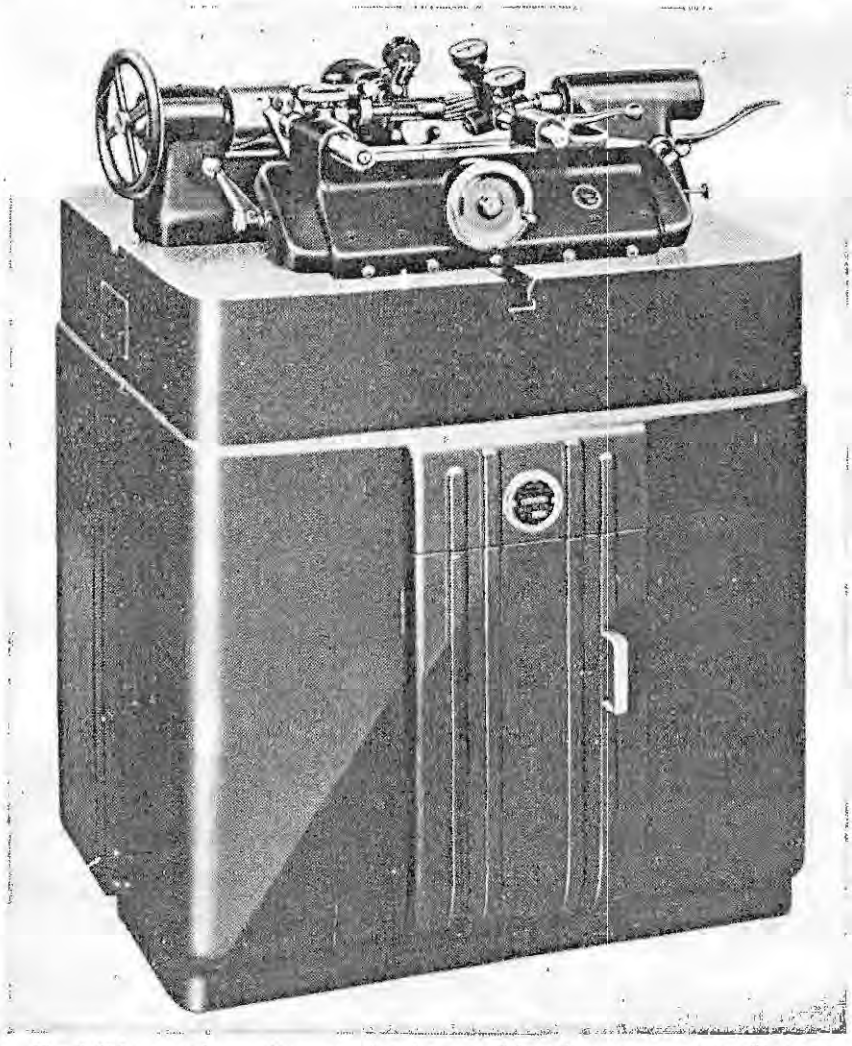


Fig. 13.10 Red Ring universal gear checker and lead comparator. *Courtesy of National Broach & Machine Co.*

ment consists of a base, headstock and tailstock centers, and an indicator bracket. Model 12CT has additional units for measuring taper also. The centers are used to hold arbors on which work is mounted. The indicator bracket carries the measuring mechanisms,

[1] Information in this, and the two sections that follow, is adapted from literature by The Fellows Gear Shaper Co. with its permission.

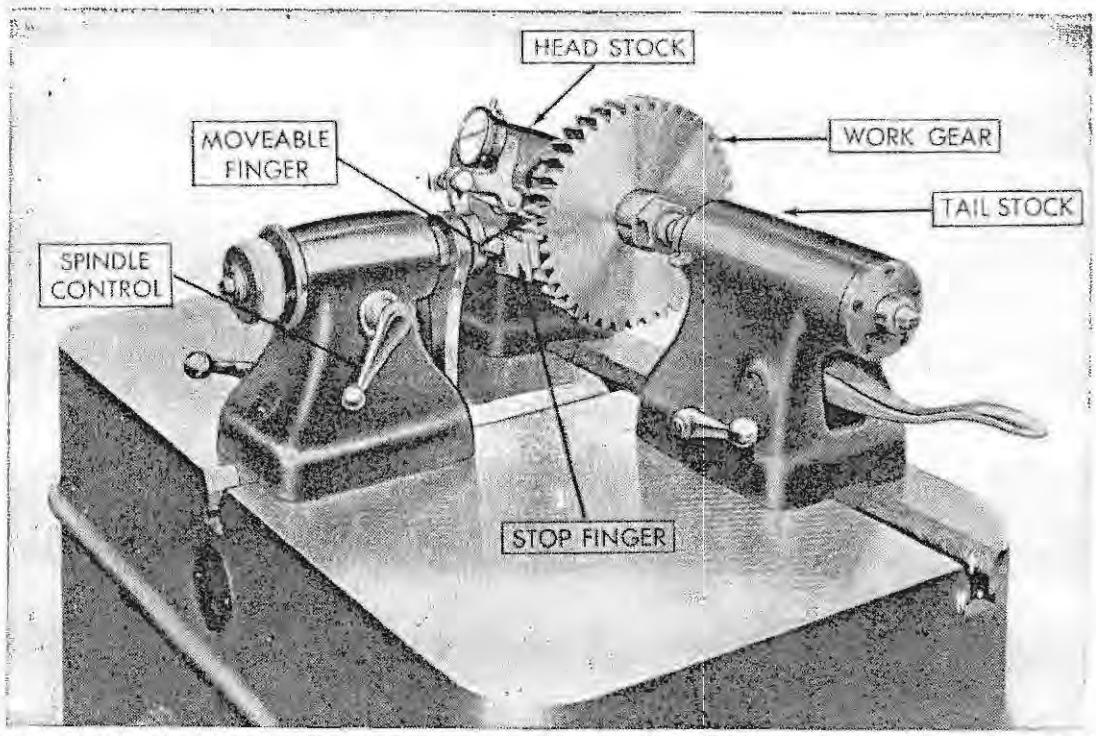


Fig. 13.11 Red Ring spacing head used to check index. *Courtesy of National Broach & Machine Co.*

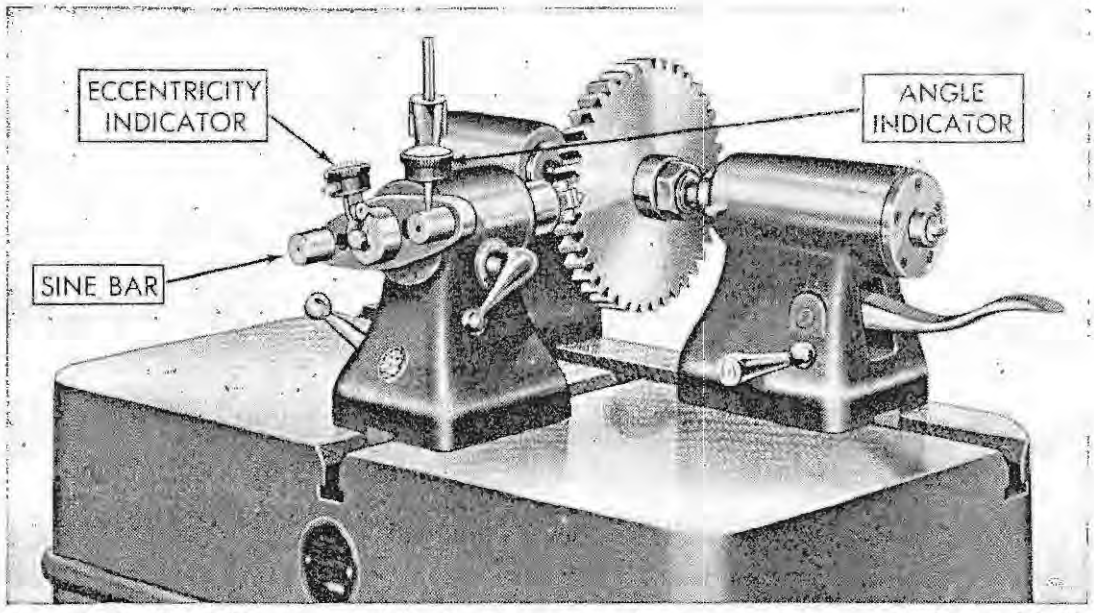


Fig. 13.12 Red Ring eccentricity head used to check eccentricity, wobble, and helix angle. *Courtesy of National Broach & Machine Co.*

and an indexing device which indexes the gear at the same time that the spindle carrying the cone pointer, or the head and measuring fingers, is withdrawn. Movement of a lever on the side of the indicator bracket operates the indexing device.

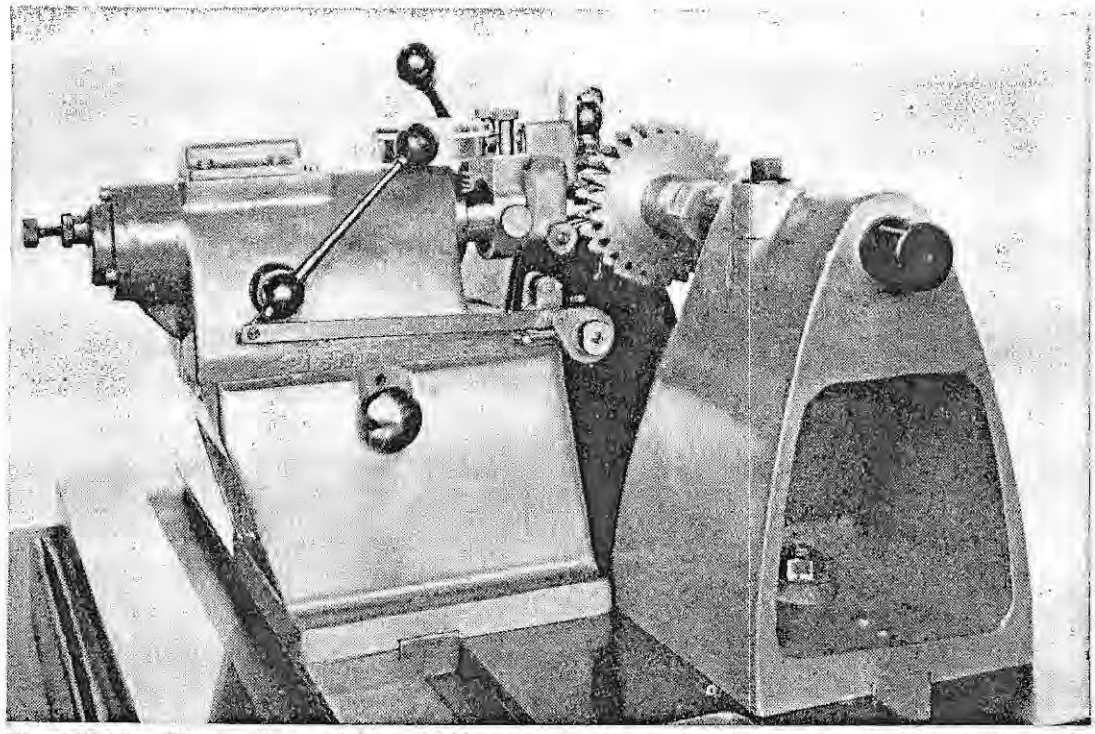


Fig. 13.13 Close view of No. 12C cone- and spacing-inspection instrument set for checking tooth spacing. *Courtesy of The Fellows Gear Shaper Co.*

Diagrams illustrating methods of checking cone, tooth spacing, and taper are shown in Fig. 13.14. Diagram II illustrates the setup for cone checking. The cone pointer Q is placed in the spindle L and is engaged with successive tooth spaces after the gear has been indexed by movement of the indexing latch D_1. Variations in the radial position of the cone pointer are read on the dial indicator U.

In diagram I, the cone pointer has been removed, and the tooth-spacing head has been placed on the end of the spindle. Stop finger M is fixed on the head, and indicator finger N_1 is flexibly mounted on a lever so that variations in tooth spacing may be read on the dial indicator. Notice that the position of the dial indicator is reversed from its former position. Springs T_1 are used to hold the gear teeth against the stop finger.

Diagram III illustrates the use of the stop finger to check taper.

The gear tooth is tested first at one end and then at the other. Additional units required by the No. 12CT instrument to do this are a handwheel, lead screw, nut to move the indicator bracket from

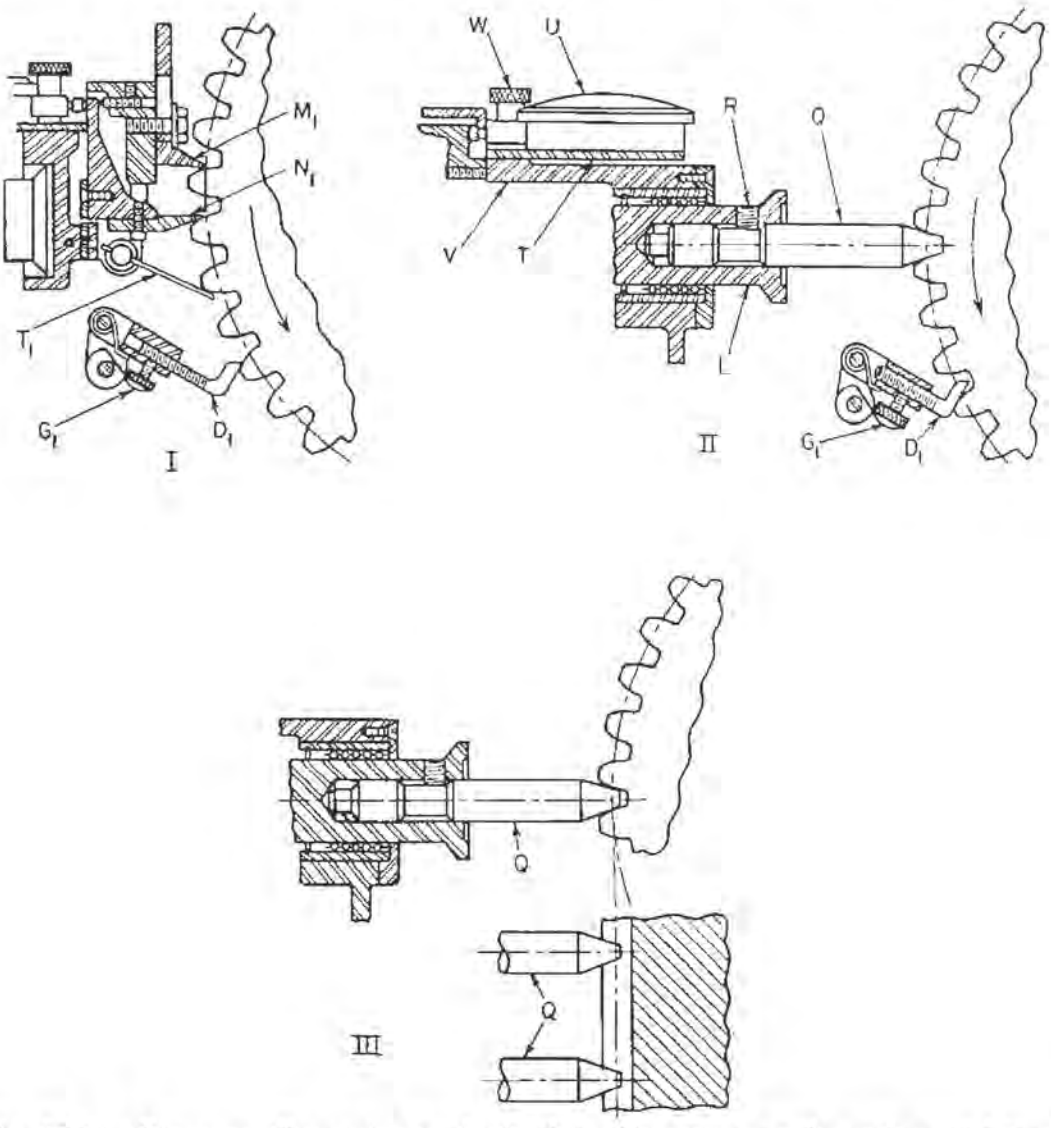


Fig. 13.14 Diagrams illustrating methods of checking cone, tooth spacing, and taper. *Courtesy of The Fellows Gear Shaper Co.*

one position to the other, and two adjustable stops to limit its travel.

Red Liner

A study of the action of gear teeth shows that there are always more than two teeth affecting the operation of a pair of mating gears. Checking each individual tooth, therefore, is inadequate as

a means of revealing the effects that errors in another pair of teeth will have on gear-tooth action. A combined inspection of all errors in tooth elements in a situation that approaches actual operating conditions, therefore, will best meet the demands of manufacturing requirements.

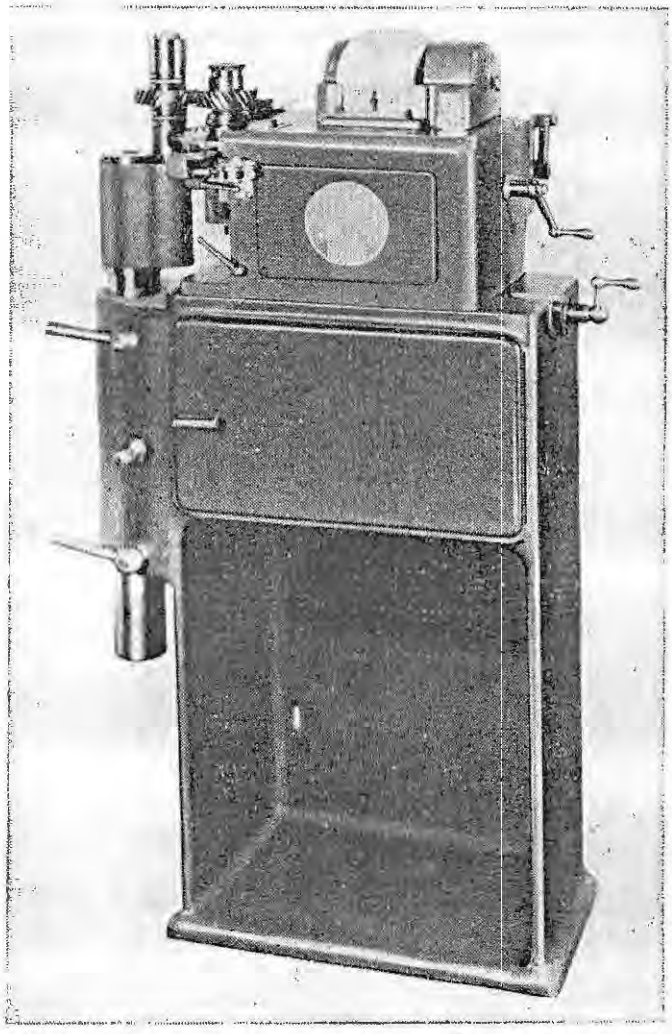


Fig. 13.15 No. 8M Red Liner for automatic gear inspection. *Courtesy of The Fellows Gear Shaper Co.*

The Fellows Red Liner, shown in Fig. 13.15, is a motor-driven machine for inspecting gears automatically which is based on the principle that errors in tooth elements will cause a change either in the velocity or in the center distance of mating gears. On the Red Liner, a master gear is flexibly mounted on a motor-driven spindle so that errors in the gear being tested will affect the center distance between the fixed work holder and the master gear. Movements

of the master gear spindle are transferred, through a multiplying lever arrangement, to a pen that traces a red line on moving chart paper. The paper has lines 0.0200 in. apart, and errors are multiplied 200 times; therefore, the distance between lines represents 0.001 in.

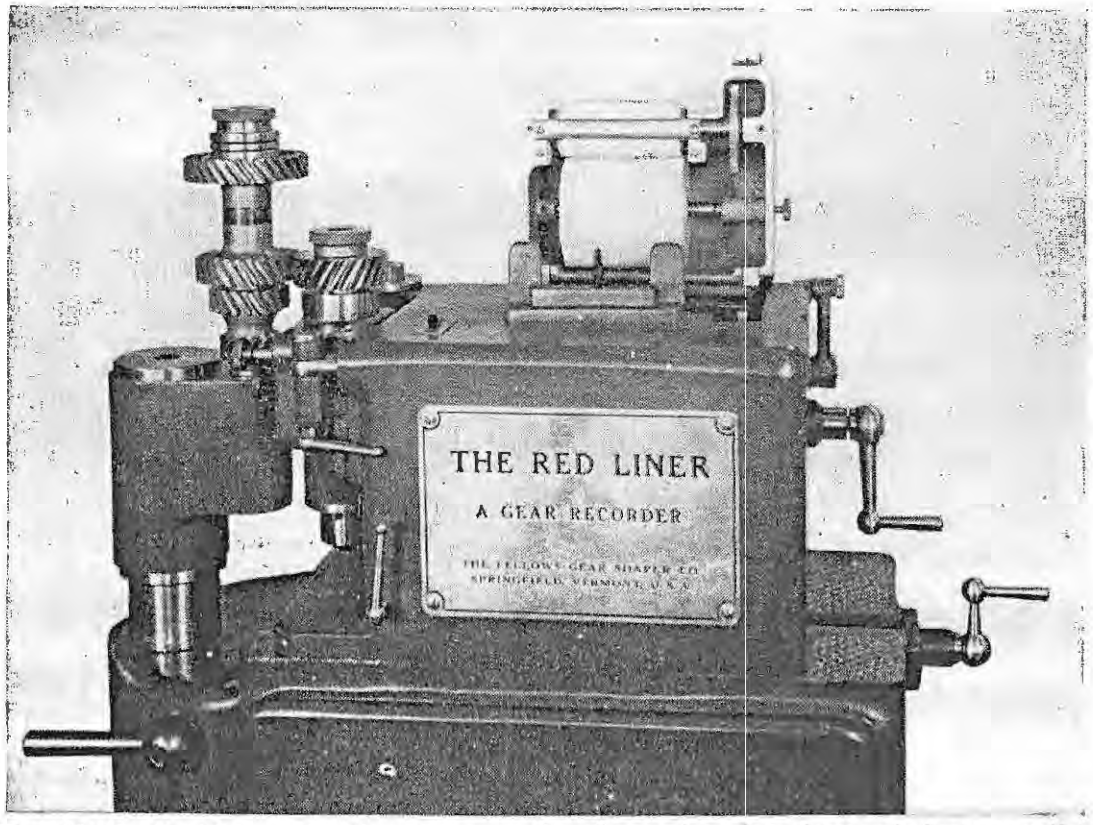


Fig. 13.16 Red Liner charting-paper carrier elevated to show how ruled-paper roll is carried and operated. *Courtesy of The Fellows Gear Shaper Co.*

A close view of work being inspected, and the cabinet carrying the master gear and charting mechanism, is shown in Fig. 13.16. The cabinet may be moved horizontally by the crank at the lower right side of this illustration to place the master gear in positive contact with the work. The other crank that is seen may be used to operate the master gear spindle by hand, if desired. The charting-paper carrier is elevated in this illustration to show how the paper is carried and operated.

The Red Liner records errors in combination on charts like those shown in Fig. 13.17. These charts may be analyzed to identify errors such as eccentricity, tooth spacing, tooth shape, etc, and may

be used to determine the location and magnitude of the errors. Conditions shown in this illustration are, reading from the left: accurate gears, eccentricity, variation in circular pitch, variations in pressure angle, fillet interference, and lack of continuous action.

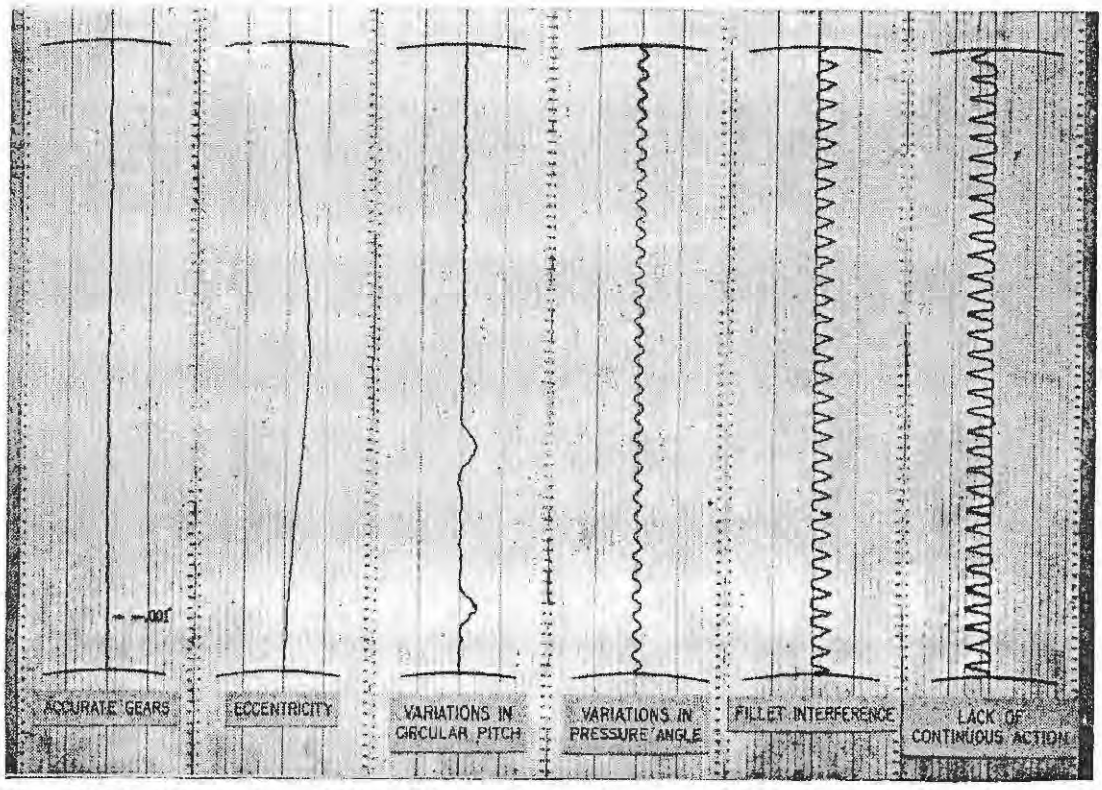


Fig. 13.17 Examples of Red Liner charts. *Courtesy of The Fellows Gear Shaper Co.*

Involute Measuring Instrument

The Fellows Involute Measuring Instrument, shown in Fig. 13.18, is a hand-operated machine for checking involute profiles. The machine is prepared for use by setting it with a calibrated master gage. Following that, the gear to be checked is placed on centers; an involute pointer is set in starting position; the gear tooth to be measured is moved into contact with the pointer; and the gear is rotated by turning the upper hand wheel at the left side of the cabinet until the pointer leaves contact with the tooth. As the gear rotates, a master involute cam, developed from a large base circle that covers the maximum capacity of the instrument, causes an indicator slide to move in unison with it at such a rate that the involute pointer will not be displaced except by reason of errors in

the tooth's profile. Errors present are read on a 0.0001-in. dial indicator that is located just in front of the work arbor in Fig. 13.18. At the same time, a graduated dial at the front of the cabinet rotates in unison with the gear and indicates the angular length of the in-

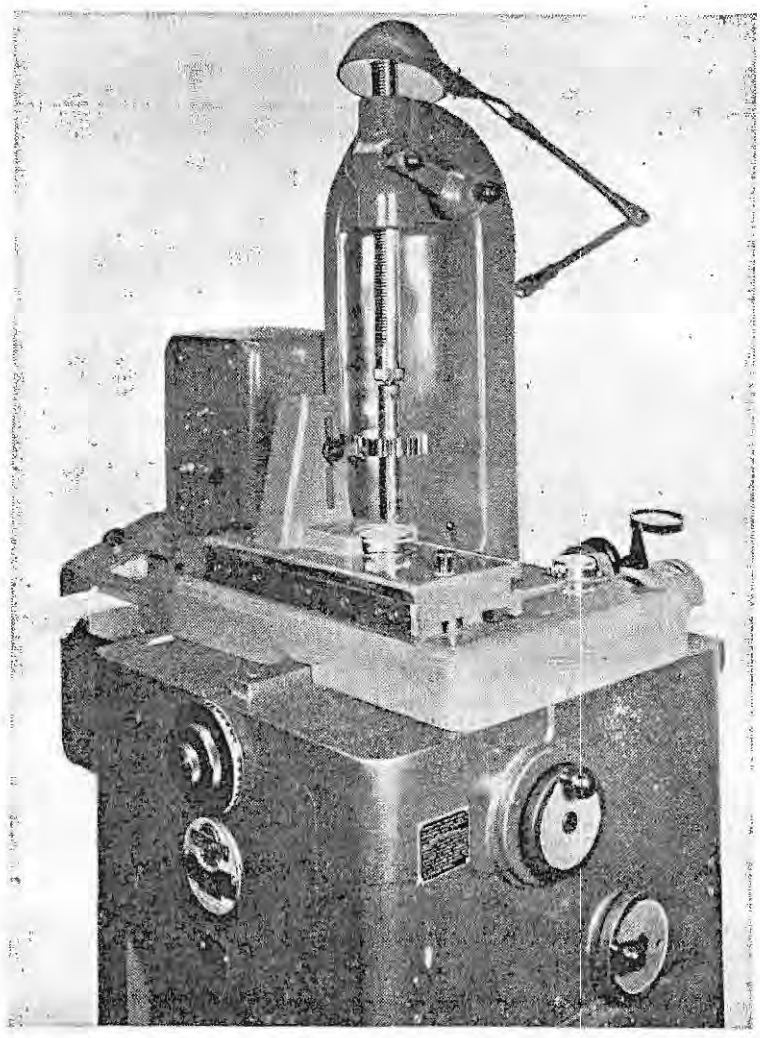


Fig. 13.18 Close view of No. 12M involute measuring instrument showing main and indicator slides. *Courtesy of The Fellows Gear Shaper Co.*

volute profile from the base circle in degrees. An electrical recorder is available for recording the involute reading on a paper chart with reference to a straight line as shown in Fig. 13.19.

Dial Indicator Gages

Dial indicators may be incorporated in special gages for inspecting gears. A dial indicator gage for checking pitch diameter and its concentricity with the bore of a gear is shown in Fig. 13.20.

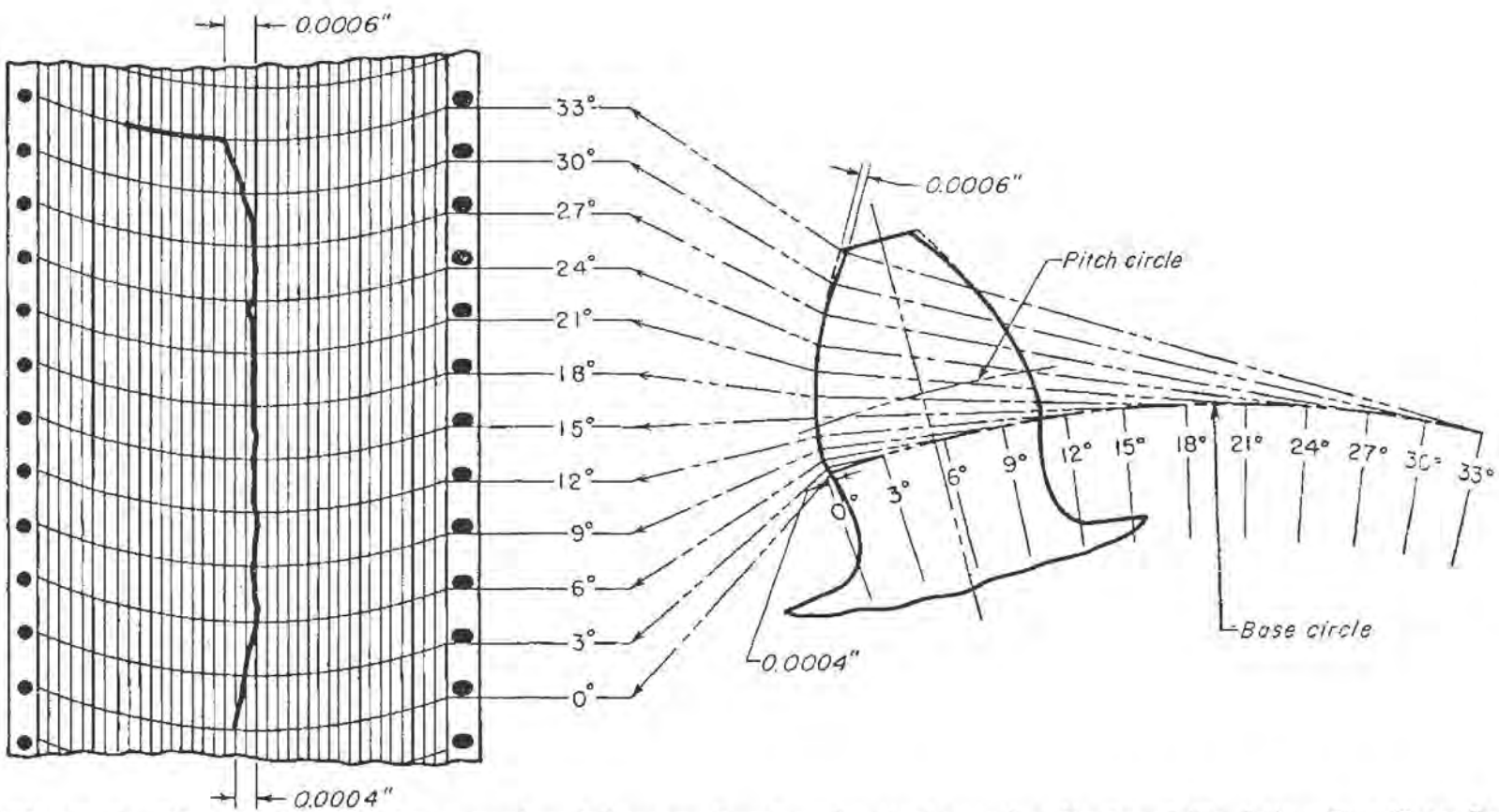


Fig. 13.19 Diagram of modified gear tooth and chart produced on electrical recorder. *Courtesy of The Fellows Gear Shaper Co.*

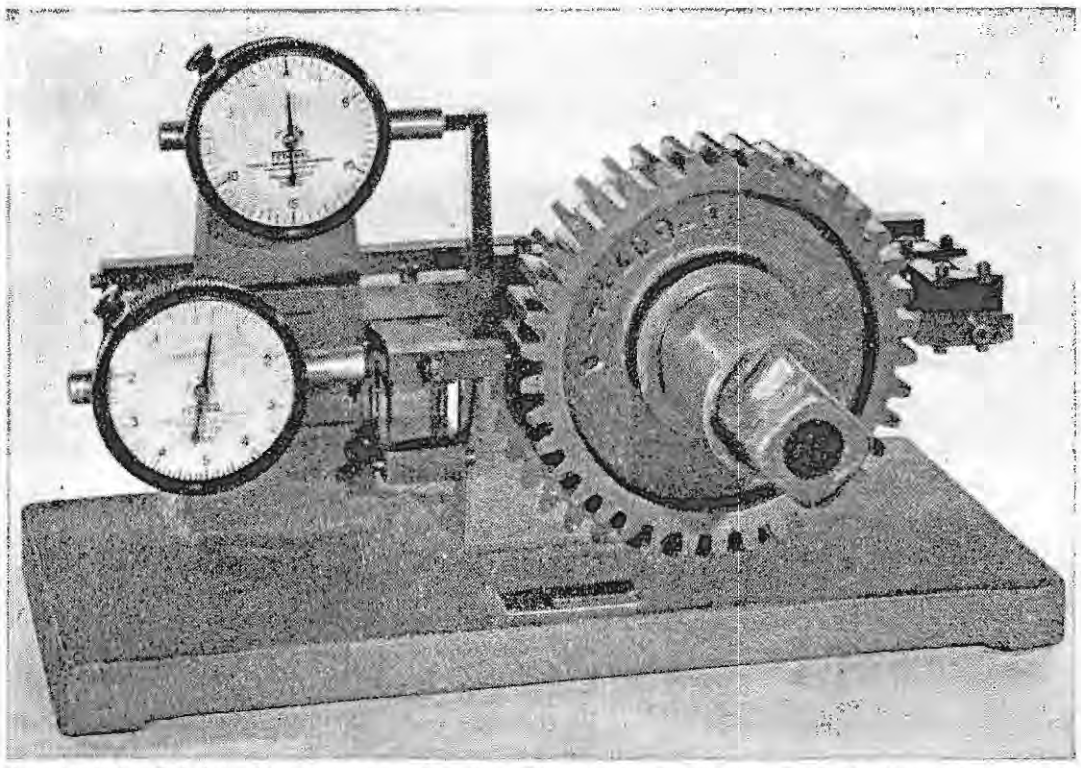


Fig. 13.20 Dial indicator gage for simultaneous checking of pitch diameter and its concentricity with bore. *Courtesy of Federal Products Corporation.*

BIBLIOGRAPHY

Colvin, Fred H., and Frank A. Stanley. "Gear Cutting Practice." 2d ed. New York: McGraw-Hill Book Company, Inc., 1943.

QUESTIONS

1. Name four types of gears in common use and state for what use each type is employed.
2. Name four American Standard gear systems.
3. Define the terms, in the following list, that apply to gearing: (*a*) pitch cylinder, (*b*) pitch circle, (*c*) pitch diameter, (*d*) pitch point, (*e*) diametral pitch, (*f*) circular pitch, (*g*) chordal pitch, (*h*) chordal thickness, (*i*) chordal addendum, (*j*) addendum, (*k*) dedendum, (*l*) whole depth, (*m*) clearance, (*n*) working depth, (*o*) face, (*p*) flank, (*q*) base circle, (*r*) line of action, (*s*) pressure angle.
4. Name two methods of measuring the thickness of gear teeth at the pitch line.

14

HARDNESS TESTING

Hardness is a comparative term that is used to designate several different qualities or combinations of qualities of materials which include resistance to scratching, abrasion, cutting, and indentation. Hardness is also related to elasticity, tensile strength, and other properties of materials. For these reasons, different methods of testing hardness have been developed, some of which are used extensively in industrial inspection.

Mohs Scale of Hardness

Scratch hardness of minerals may be determined by a scale that was established by Mohs in 1820. This scale, and a scale of corresponding Knoop hardness numbers are given in Table 11. In the Mohs scale, minerals are designated by numbers from 1 to 10; the mineral in any division of the scale will scratch those in all lower classes and will be scratched by all those in higher classes. This test is used, primarily, to measure the hardness of nonmetallic minerals. The scale of Knoop hardness numbers for the same minerals, also given in Table 11, was determined by the Knoop hardness test which is described later in this chapter.

Turner's Sclerometer

Turner's Sclerometer is an instrument that is used to test hardness by scratching the polished surface of a specimen with one forward

and one return stroke of a diamond under load. The hardness number is the weight in grams that is required to produce a scratch of standard width.

File Test

The hardness of heat-treated steel may be tested by filing the surface of the work with a firm, slow stroke. The file will not "bite" into hard steel, but it will cut soft steel readily. This test is unreliable because the operator's "feel" is the only means of judging the degree of hardness in the specimen. Two methods to improve its reliability have been suggested: (*a*) the use of a set of files tempered to different hardness for testing the work, and (*b*) the use of a set of comparison standards drawn to different tempers as a basis for comparing and judging hardness of the work.

Brinell Hardness Tester

The Brinell test consists of indenting the specimen with a 10-mm steel ball under a load of 3,000 kg for 30 sec. The diameter of the impression is then measured with a Brinell microscope, and the hardness number is read in Table 12. This hardness number is equal to the load on the ball divided by the area of the impression, and it is obtained from the formulas

$$H = \frac{K(r + \sqrt{r^2 - R^2})}{2\pi r R^2}$$

or

$$H = \frac{K}{2\pi r d}$$

where H = hardness number.
K = load, kgs.
r = radius of the ball.
R = radius of the indentation.
d = depth of indentation.

A hand-operated Brinell hardness tester, recommended for laboratory and limited production use, is shown in Fig. 14.1. The machine is a hydraulic press with a downward acting ram that applies load to the ball indenter. Specimens to be tested should be finished well enough for the edge of the indentation to show clearly.

Fig. 14.1 Olsen type 1 hand-operated Brinell hardness tester. *Courtesy of Tinius Olsen Testing Machine Co.*

In operating the machine, the specimen is placed on the anvil and raised into contact with the ball; the relief valve is closed; and the hand-operated hydraulic pump is stroked gently until the accumulator check weights rise slowly. At this point, the hydraulic gage indicates the Brinell load. The pressure is allowed to stand as long as desired; the relief valve is opened to release the pressure; the specimen is removed from the machine; and the indentation is measured. If the indentation is oval, both axes are measured and their average is used. The standard load for iron and steel is 3,000 kg; and for copper, brass, and the softer metals it is 500 kg. Hardness numbers for this load are included in Table 12.

The diameter of the impression, made by the Brinell ball, is measured with a Brinell microscope that contains a scale having 0.01-mm graduations. The Brinell microscopes in Figs. 14.2 and 14.3 illuminate the impression with a small electric lamp and magnify it 20 diameters.

A motor-driven production Brinell hardness testing machine, recommended for tests on a 100 per cent inspection basis, is illustrated in Fig. 14.4. Other sizes and types of the Brinell machine are designed for high-speed production testing, for testing soft and thin materials, and for other specialized applications. Tungsten carbide Brinell balls are available for testing very hard materials.

Rockwell Hardness Tester

One model of the Rockwell hardness tester is shown in Fig. 14.5. This test consists of indenting a specimen by: (*a*) applying an initial minor load of 10 kg to set zero on the dial gage; and (*b*) applying a final major load of 60, 100, or 150 kg to the penetrator. The hardness number, which is read on the gage, is based on the increment

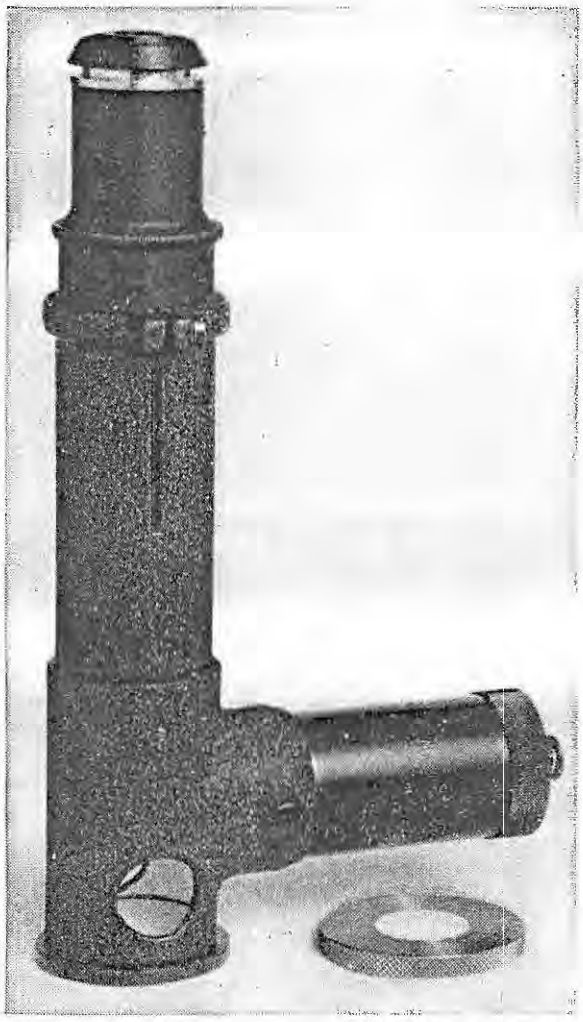


Fig. 14.2 Brinell microscope (battery operated). *Courtesy of Tinius Olsen Testing Machine Co.*

of depth which results from increasing the minor load pressure to the major pressure as illustrated in Fig. 14.6.

The micrometer dial gage of a normal Rockwell hardness tester is shown in Fig. 14.7. This gage has a "reversed" scale; that is, the pointer of the gage moves counterclockwise as load is applied to the penetrator so that a low reading results from deep penetration in

soft metals, and a high reading results from shallow penetration in hard metals. The gage is read after the major load has been released, but with the minor load still on the penetrator so that spring in the

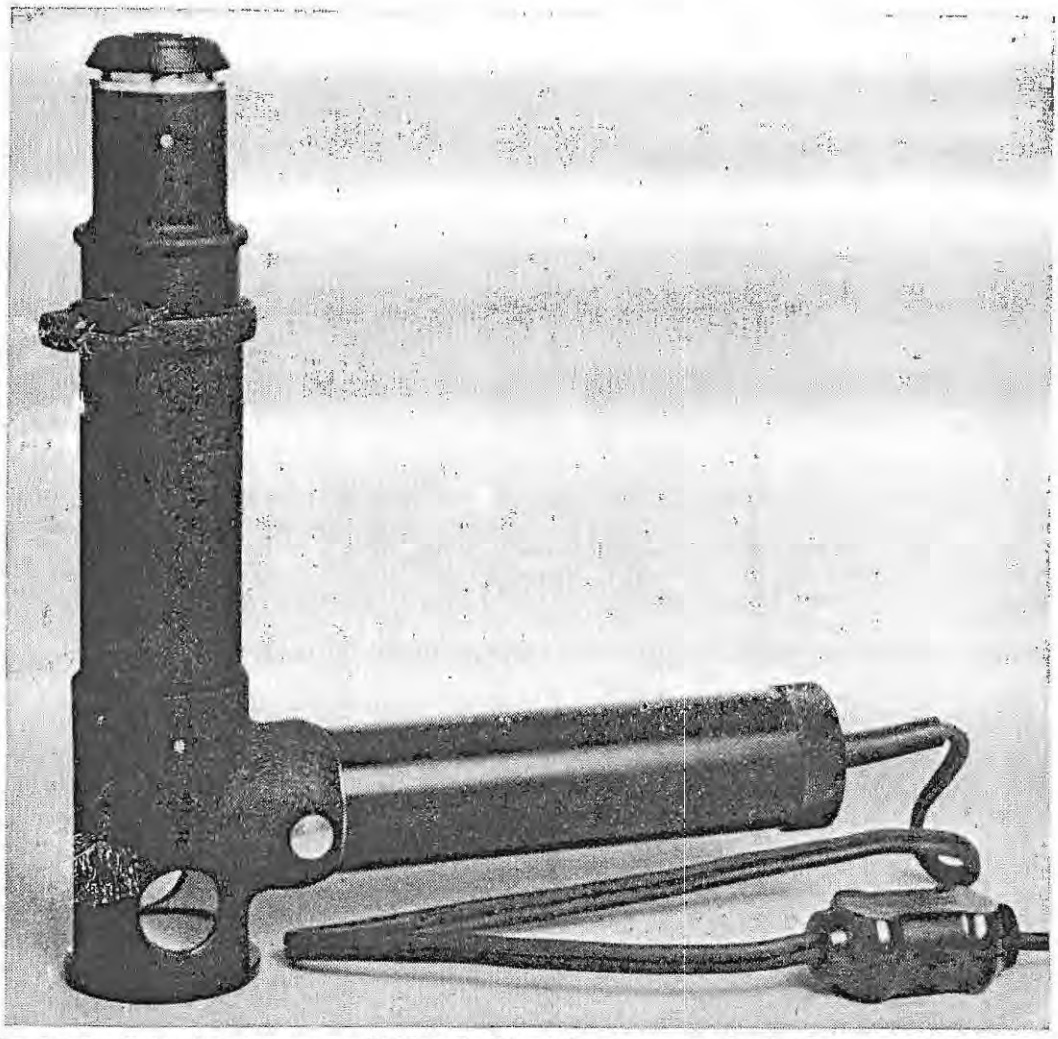


Fig. 14.3 Brinell microscope (110-volt 60-cycle a-c operation). *Courtesy of Tinius Olsen Testing Machine Co.*

machine and elasticity of the specimen will not influence the result of the test.

A $\frac{1}{16}$-in. steel-ball penetrator with a 100-kg load is used for testing such materials as brass, bronze, soft steel, and annealed alloy and tool steels. All readings with the $\frac{1}{16}$-in. ball and 100-kg load are read on the red *B* scale, and the letter *B* must be prefixed to the numbers.

A spheroconical diamond Brale penetrator and a 150-kg load is used for testing hardened steels and other hard metals. All readings

with the Brale penetrator and the 150-kg load are read on the black *C* scale, and the letter *C* must be prefixed to the numerals.

The Brale penetrator and the 60-kg load are used to test ex-

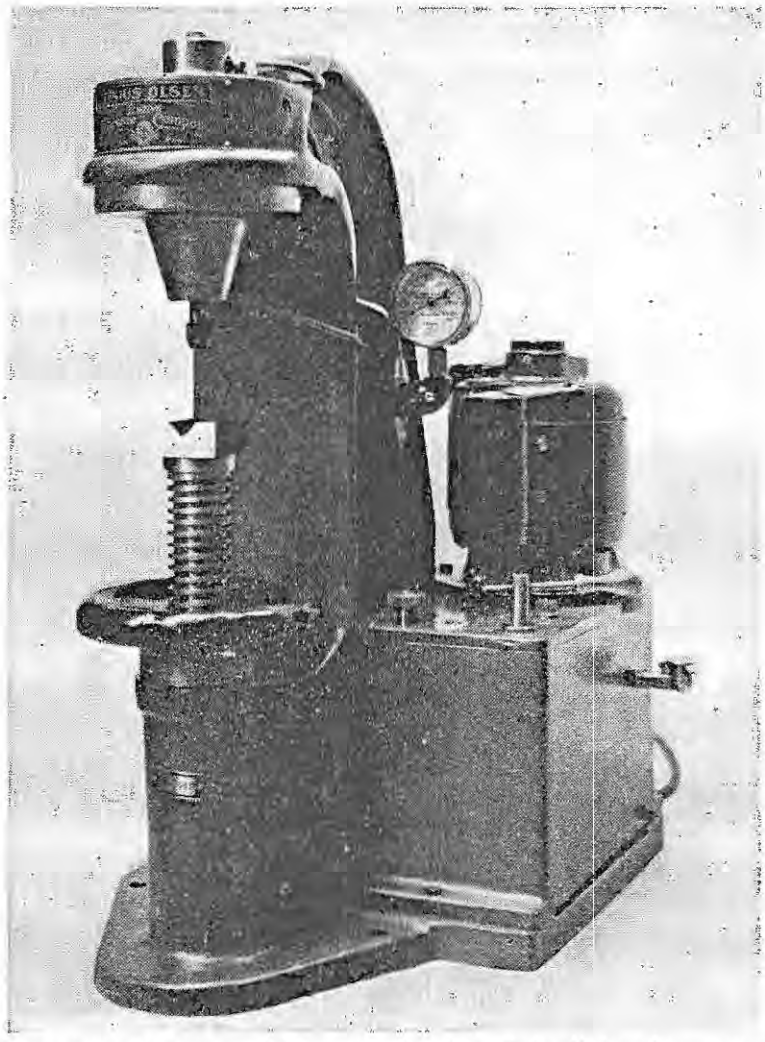


Fig. 14.4 Olsen type 1 motor-driven production Brinell hardness testing machine. *Courtesy of Tinius Olsen Testing Machine Co.*

tremely hard metals, such as tungsten carbides; and the $\frac{1}{16}$-in. steel-ball penetrator and 60-kg load are used extensively to test sheet brass.

Special penetrators of $\frac{1}{8}$-, $\frac{1}{4}$-, and $\frac{1}{2}$-in. steel balls are available for testing soft materials; and the scale designation, depending on the kind and size of the penetrator and the load used, is given in Table 13.

Standard and special anvils and rests are available for supporting work of different shapes and sizes.

The usual and most precise method of operating the Rockwell hardness tester is described with reference to the key numbers in Fig. 14.8:

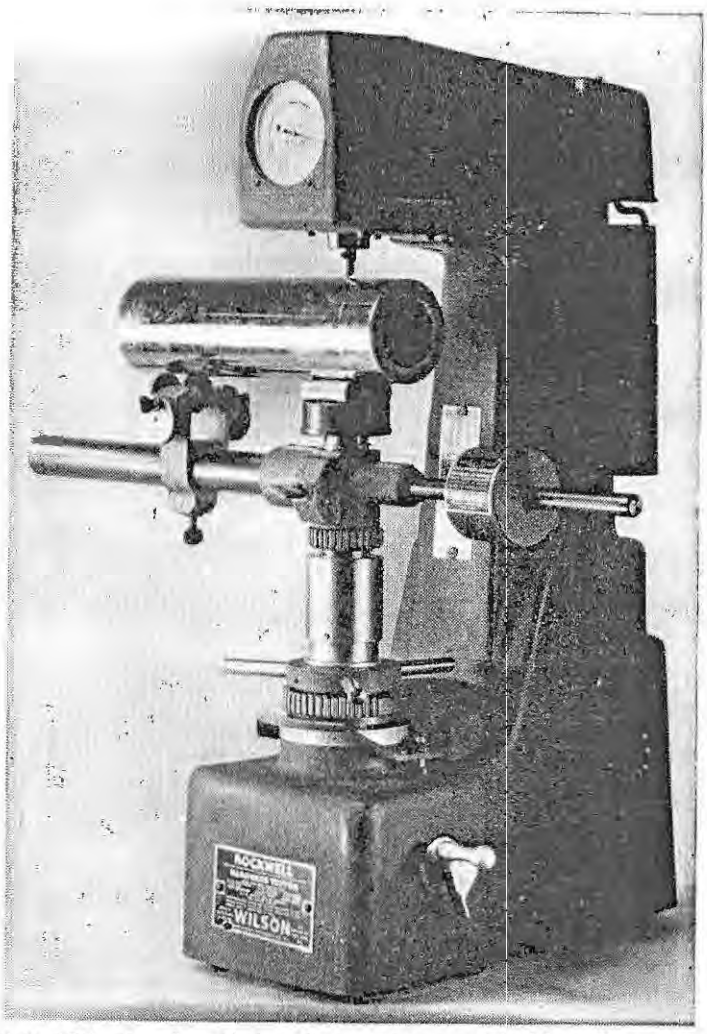


Fig. 14.5 Model 4JR Rockwell hardness tester with Vari-Rest. *Courtesy of Wilson Mechanical Instrument Co., Inc.*

1. Before starting the test, see that the crank handle (6) is turned forward; that is, counterclockwise to lift the weights.
2. Place the specimen securely upon the anvil or table (1).
3. Turn the capstan wheel (2) to elevate the specimen into contact with the penetrator and farther until small pointer (8) of the indicating gage is nearly vertical and slightly to the right of the dot, then turn still farther until the large pointer (5) points vertically upward. This applies the minor load.

4. Turn zero adjuster (3) of gage till the "Set" arrow on dial is exactly back of the large pointer.
5. Push down on depressor bar (4) to apply the major load.
6. Pull crank handle (6) forward, lifting the major load, but leaving the minor load still applied.
7. Read the Rockwell hardness number.
8. Turn capstan wheel (2) to lower the specimen away from the penetrator.

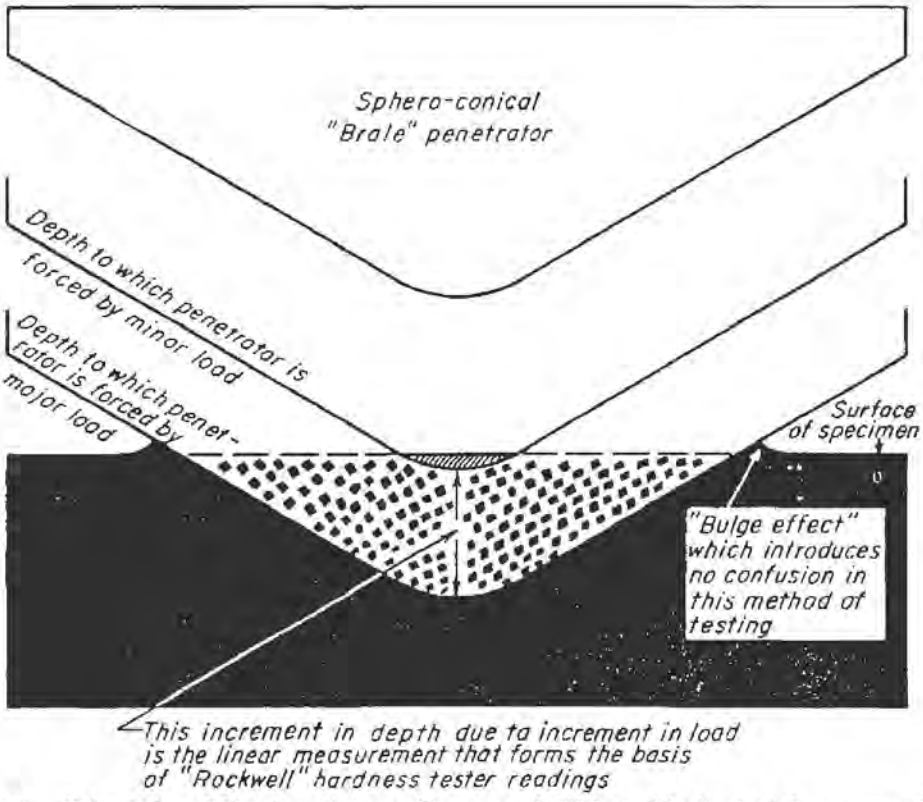

Sphero-conical
"Brale" penetrator
Depth to which penetrator is forced by minor load
Depth to which penetrator is forced by major load
Surface of specimen
"Bulge effect" which introduces no confusion in this method of testing
This increment in depth due to increment in load is the linear measurement that forms the basis of "Rockwell" hardness tester readings

Fig. 14.6 Principle of Rockwell test. *Courtesy of Wilson Mechanical Instrument Co., Inc.*

A Zerominder method of speed testing permits zero adjustment of the gage while the major load is applied to speed up quantity inspection testing. Consult the manufacturer's instructions for information on this method.

Rockwell Superficial Hardness Tester

The Rockwell Superficial hardness tester is designed for testing sheet metal too thin to test on the normal machine. It employs a $\frac{1}{16}$-in. ball, or an *N* Brale penetrator, and major loads of 15, 30,

or 45 kg. Ball penetrators $\frac{1}{8}$, $\frac{1}{4}$, and $\frac{1}{2}$ in. are available for special applications. The scale designation for use with this machine, depending on the kind and size of the penetrator and the load used, is given in Table 14.

Tables 15 and 16 are conversion tables that give approximate relationships between hardness values determined on Rockwell and Rockwell Superficial hardness testers, and values determined on other testers. The relationship between hardness and tensile strength of steel is given also.

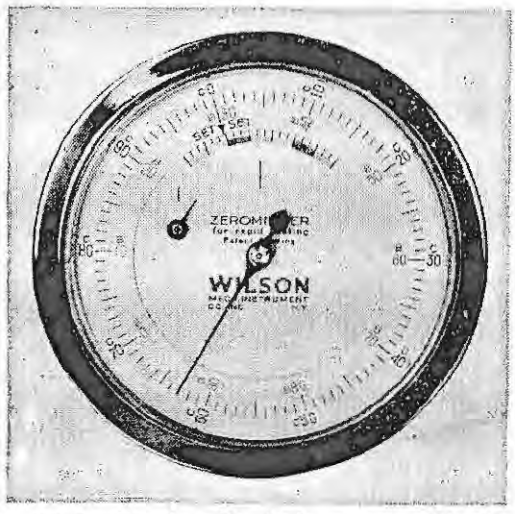


Fig. 14.7 Rockwell dial gage with Zerominder scale. *Courtesy of Wilson Mechanical Instrument Co., Inc.*

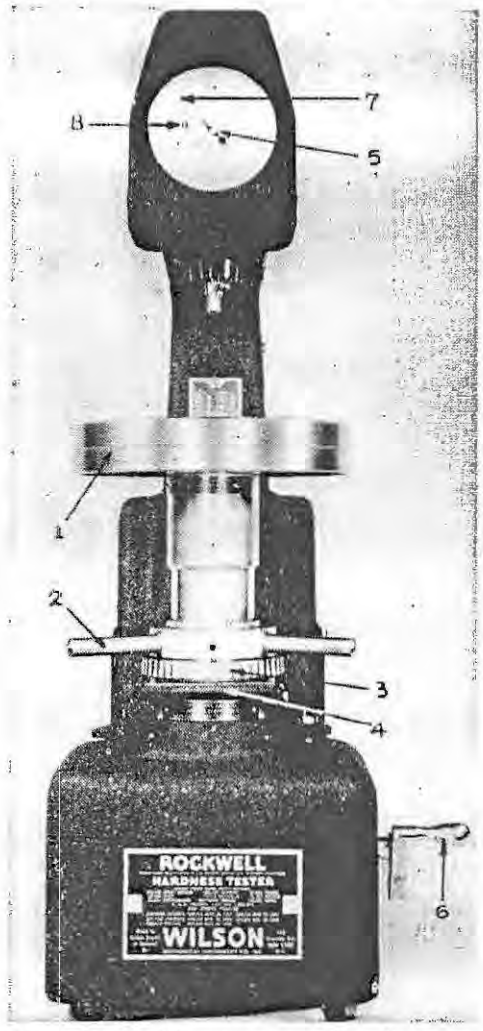


Fig. 14.8 Key to operating instructions for Rockwell hardness tester. *Courtesy of Wilson Mechanical Instrument Co., Inc.*

Vickers Hardness Test

The Vickers test is similar, in principle, to the Brinell test. It employs a diamond indenter in the form of a square-based pyramid, having an angle of 136 deg between its faces, which is applied to the specimen with a load of from 5 to 120 kg, depending on the hardness and thickness of the part. The Vickers hardness number equals the load in kilograms divided by the area of the indentation

in square millimeters. The diagonals of the square indentation are measured with a microscope and averaged, and the hardness number is obtained from a table or by calculation from the formula

$$H = \frac{1.854L}{d^2}$$

where H = the Vickers hardness number.
L = the load, kg.
d = the average diagonal, mm.

Knoop Hardness Test

The Knoop test employs light loads and microscopic indentations to measure the hardness of small precision parts, thin sheet metal, small-diameter wire, glass, porcelain, and the crystals and particles of microstructures. The Knoop indenter is a diamond in the form of a diamond-shaped-base pyramid that has an included longitudinal angle of 172 deg 30 minutes and an included transverse angle of 130 deg. The ratio of the long and short diagonals is approximately 7:1. The applied loads range from 10 to 3,600 grams. The Knoop hardness number equals the load in kilograms divided by the projected area of the indentation in square millimeters. This number may be determined by measuring the long diagonal of the impression with a microscope, and consulting a table computed for a theoretically perfect indenter; or it may be calculated from the formula

$$I = \frac{L}{A_p}$$

where I = Knoop hardness number.
L = load, kg, applied to the indenter.
A_p = unrecovered projected area of indentation, sq mm.

Monotron Hardness Test

The Monotron test forces a $\frac{3}{4}$-mm hemispherical diamond penetrator into the material to a depth of 0.0018 in., and the load which is required to produce the impression is the Monotron hardness

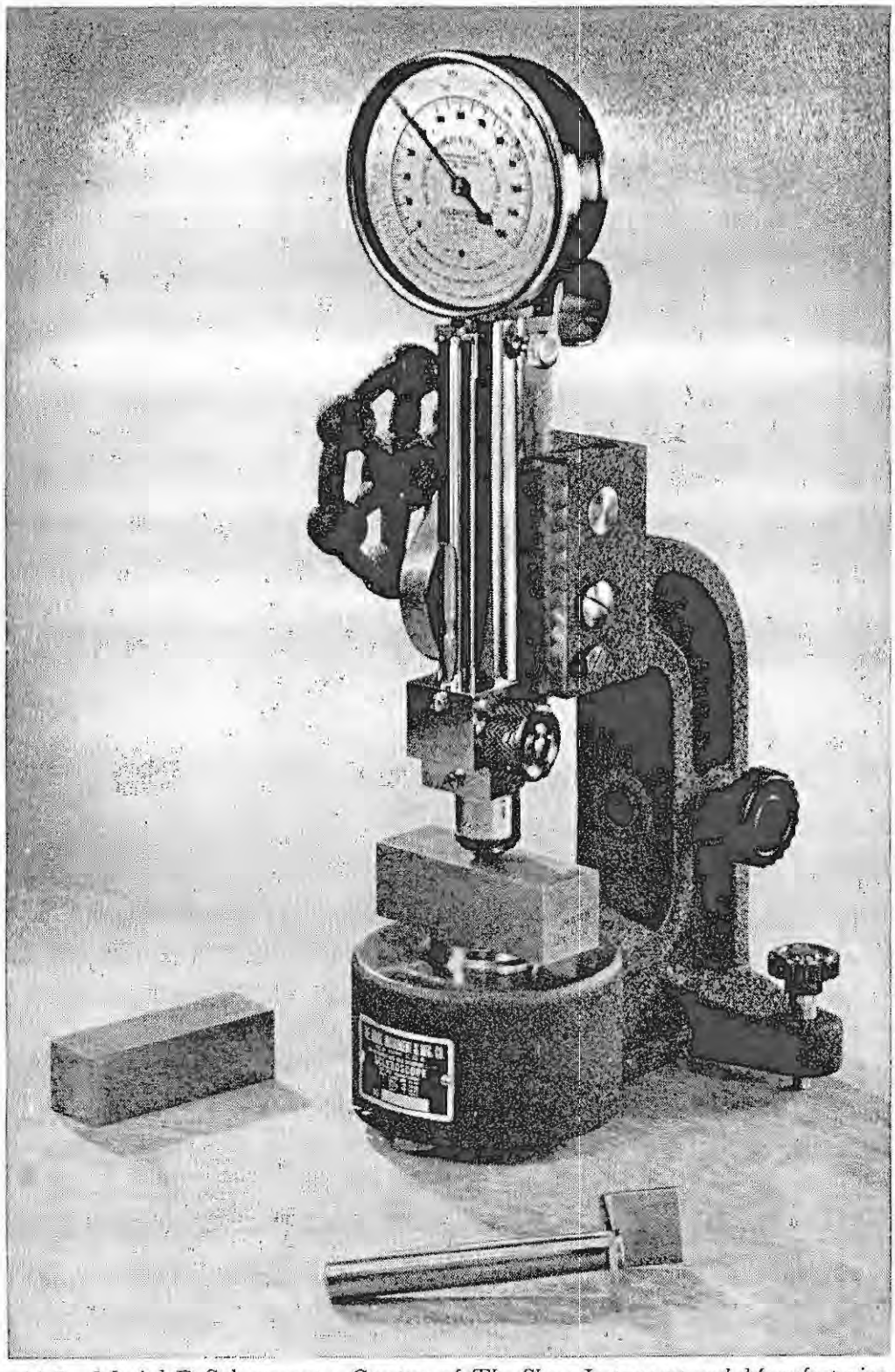


Fig. 14.9 Model D Scleroscope. *Courtesy of The Shore Instrument and Manufacturing Co.*

number. The Monotron hardness tester has two dial gages on its head. The upper one indicates the applied load, and the lower indicates the depth of penetration.

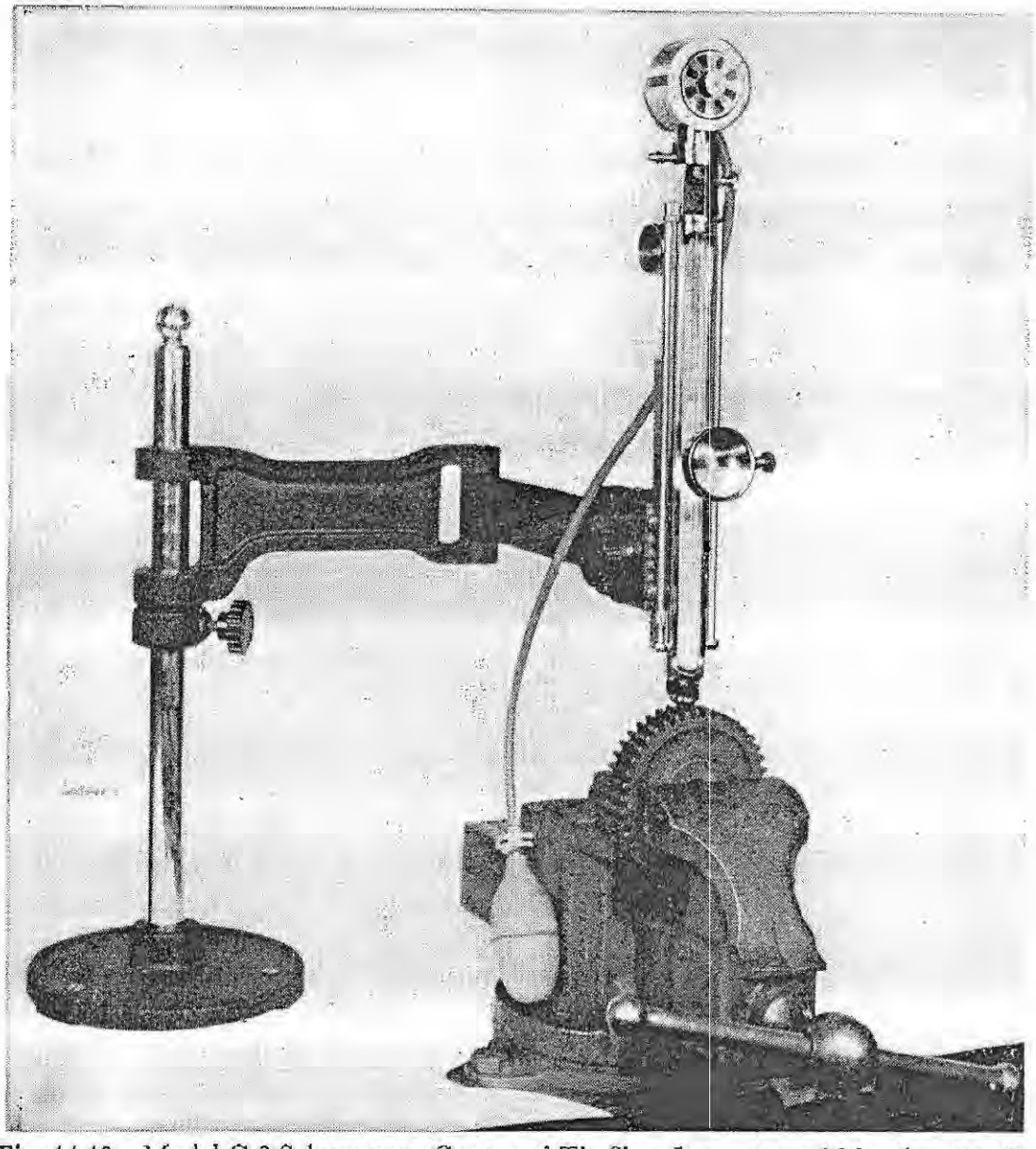


Fig. 14.10 Model C-2 Scleroscope. *Courtesy of The Shore Instrument and Manufacturing Co.*

Scleroscope Hardness Test

The Scleroscope measures the height of rebound of a free-falling diamond-tipped hammer from the surface of the specimen being tested. The test actually measures elasticity, but hardness is measured indirectly because the two properties are related. The Model D Scleroscope, illustrated in Fig. 14.9, measures the height of re-

bound on a dial gage; and the Model C-2 (Fig. 14.10) measures it on a scale at the back of the glass tube which encloses the hammer.

The Model D Scleroscope is operated in the following manner:

1. Level the instrument, with the leveling screws at the back of the base, so that the plumb rod swings freely, and its lower end centers in the hole beneath it. The diamond-tipped hammer is on the end of the plumb rod.
2. Loosen the binding screw at the top and right-hand side of the barrel and remove the dial head.
3. Turn the hand knob on the left side of the instrument to raise the barrel off the anvil.
4. Turn the top of the knurled knob, at the lower right side of the tube, toward the front of the instrument as far as it will go. Then turn it in the opposite direction as far as it will go. Do this several times to be sure that the hammer will fall freely.
5. Replace the dial head, seating the flange securely on the barrel, and tighten the binding screw. The instrument is ready for use.
6. Raise the barrel far enough to permit (*a*) cleaning the anvil, and (*b*) placing the work on the anvil. Be sure that the work is seated firmly and that the surface to be tested is in a horizontal plane.
7. Lower the barrel and dial head until the lower end of the barrel is seated firmly on the specimen. Maintain a firm uniform pressure, by hand, throughout the test.
8. Turn the top of the knurled knob, at the lower right side of the tube, toward the front of the instrument as far as it will go.
9. Turn the knob in the opposite direction, gently, until the hammer drops in the barrel.
10. Turn the top of the knob toward the front of the machine again until the pointer comes to rest at the hardness number indicated on the dial.
11. The pointer and hammer will remain fixed in position until the knob is turned to set the instrument for another test.

Do not drop the hammer on a spot more than once. The hammer's blow hardens the specimen, and a different reading will result each time a blow is struck.

The test blocks that are furnished with this instrument are not to calibrate it. There is nothing to get out of order in this respect. They are used only to see that the instrument is in working order.

The head of the Scleroscope may be removed from its stand to measure the hardness of large pieces that cannot be tested with the head mounted on the stand.

The Model C-2 Scleroscope is operated as follows:

1. Set up the instrument and specimen. Maintain a firm uniform pressure on the specimen with the head of the instrument throughout the test.
2. Squeeze the bulb to raise the hammer to the top of the glass tube where it will be engaged by a latch.
3. Squeeze the bulb again to release the latch. This permits the hammer to fall on the specimen and to rebound after the impact to a height that depends on the hardness of the specimen.
4. Squeeze the bulb a third time after the hammer has reached the top of its rebound to reset the hammer before it can strike the work a second time. Read the hardness at the height of the rebound on the scale at the back of the tube.

QUESTIONS

1. Hardness is a comparative term that is used to designate several different qualities or combinations of qualities of materials. Name four such qualities.
2. Name a hardness-testing instrument that employs a diamond to scratch the polished surface of specimens.
3. Name a nonprecision test for judging the hardness of heat-treated steel.
4. Name a hardness test that indents the work with a 10-mm steel ball.
5. Name a hardness test that indents the work with a conical diamond penetrator.
6. Name a hardness test that measures hardness by the rebound of a diamond-tipped hammer.

15

MEASUREMENT OF SURFACE FINISH

The *surface* of an object is its exterior boundary. A surface that has been finished by one of the metal-cutting processes is composed of numerous small ridges and valleys that deviate from a nominal surface; and these irregularities are responsible, to a great extent, for the appearance of the surface and its suitability for an intended application in machine construction. Although appearance is often used to judge the quality of a surface, it is an unreliable measure because two surfaces that appear identical to the eye may differ considerably in roughness; and two surfaces which are alike may differ in appearance. In order to control the quality of finished surfaces, therefore, it is necessary to have methods of classifying, specifying, and measuring deviations of actual from nominal surfaces.

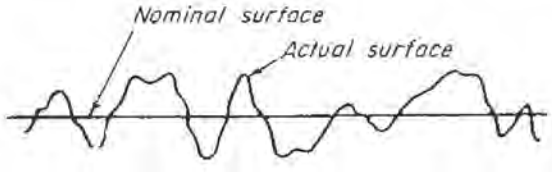


Fig. 15.1 Representation of nominal and actual surfaces.

Elements of Surface Finish

A nominal surface is a theoretical, geometrically perfect surface which is an average of the irregularities that are superimposed on it. These irregularities consist of surface flaws, waviness, and roughness. Figure 15.1 illustrates the terms nominal surface and actual surface.

Surface flaws consist of scratches, holes, cracks, checks, porosity,

and similar imperfections that occur at relatively infrequent intervals. They may be observed directly or with the aid of a penetrating dye or other material that makes them visible for examination and evaluation.

Waviness consists of feed marks, made by a cutting tool, or other irregularities that occur in the form of waves caused by vibration or deflection in the work, the cutting tool, or the machine. Waviness is pronounced enough for its height and width to be measured in inches, or it may be expressed as per cent of contact area when tested with a surface plate or other reference surface.

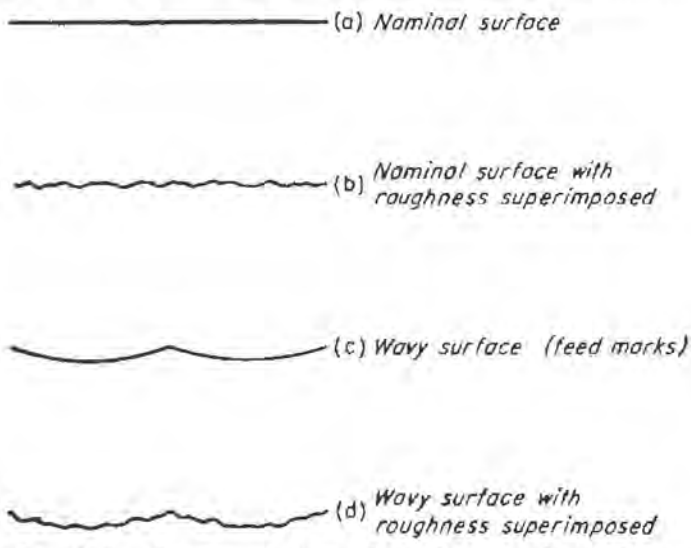

(a) Nominal surface
(b) Nominal surface with roughness superimposed
(c) Wavy surface (feed marks)
(d) Wavy surface with roughness superimposed

Fig. 15.2 Representation of waviness and roughness.

Roughness consists of marks made by a cutting tool that give machined surfaces their characteristic appearance. It is considered as being superimposed on a nominal or wavy surface and determines what is usually called the "finish" on a machined surface. Roughness is measured by determining its height and width in microinches. One microinch, abbreviated μin., equals one millionth (0.000001) of an inch. Figure 15.2 illustrates the terms waviness and roughness.

Roughness is usually measured on a small area only. It is measured perpendicular to the nominal surface and, customarily, in the direction that gives the greatest value. Usually, this is across the lay.

Lay is the direction of the tool marks that make up the characteristic pattern on a machined surface.

Root-mean-square Value

The roughness of a surface may be measured by determining the maximum value of its irregularities. For most purposes, however, it is more useful to determine their average deviation from a nominal surface.[1] Although any average may be used, the root-mean-square value is commonly employed. This value is expressed as microinches rms, or μin. rms.

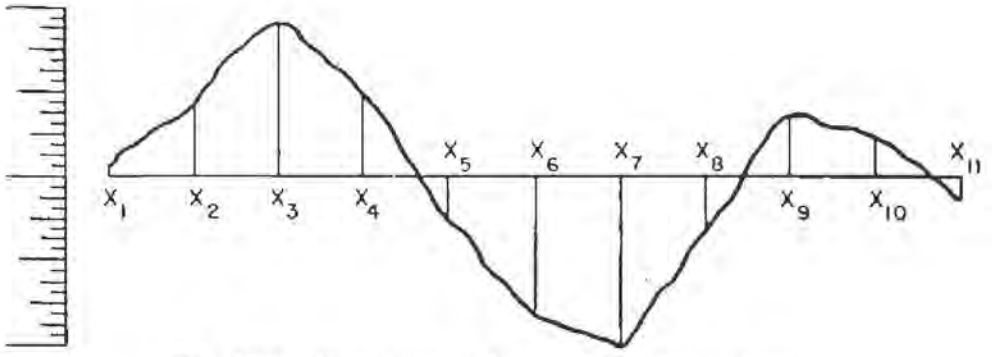


Fig. 15.3 Calculation of root-mean-square value.

The *root-mean-square value* of a set of numbers is the positive square root of the arithmetic mean of the squares of the numbers in the set. The formula for computing this value is

$$\text{rms} = \sqrt{\frac{x_1^2 + x_2^2 + \cdots + x_n^2}{n}}$$

where rms = root-mean-square value.
$x_1, x_2, \ldots, x_n$ = numbers in the set.
n = number of numerals in the set.

For example, the curve in Fig. 15.3 represents a magnified profile of a surface. Its root-mean-square value is found by drawing a centerline through the curve, drawing vertical lines to connect the curve and center line at regular intervals, and measuring the vertical distances. The distances above the center line are designated as positive, and those below it as negative. The measurements are substituted in the formula, and the root-mean-square value is computed as shown below Fig. 15.3. It is not necessary to perform

[1] The Society of Automotive Engineers standard on surface finish specifies the use of the arithmetical average deviation from a nominal surface.

this computation in practice because the instruments that are used to measure surface finish do it automatically. The root-mean-square value is used in measuring roughness because it emphasizes the greatest irregularities.

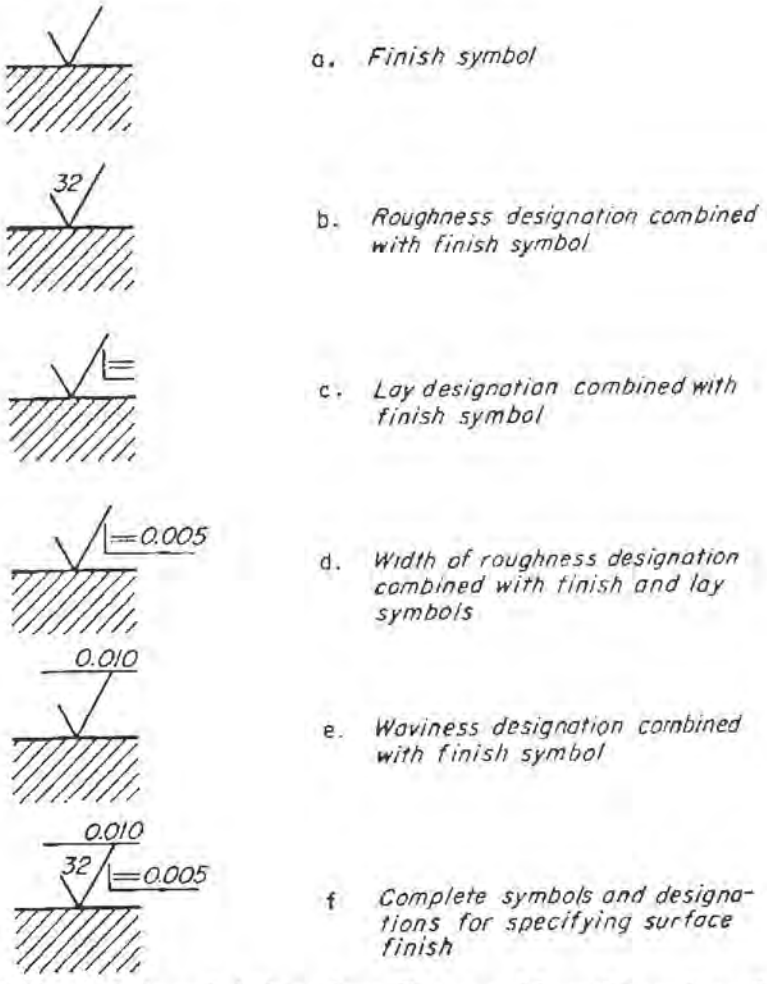

a. Finish symbol
32
b. Roughness designation combined with finish symbol
c. Lay designation combined with finish symbol
=0.005
d. Width of roughness designation combined with finish and lay symbols
0.010
e. Waviness designation combined with finish symbol
0.010
32
=0.005
f Complete symbols and designations for specifying surface finish

Fig. 15.4 Finish symbols and designations. Extracted from "American Standard Surface Roughness, Waviness, and Lay" (ASA B46.1-1947), *with the permission of The American Society of Mechanical Engineers.*

Drawing Symbols for Specifying Surface Finish

Roughness, lay, and waviness may be designated on drawings and in written specifications by the use of standardized symbols.[1]

The symbol used to designate finish is the check mark shown in Fig. 15.4*a*. The point of the symbol may be placed on the line rep-

[1] Extracted from "American Standard Surface Roughness, Waviness and Lay," Part I (ASA B46.1-1947), with the permission of the publisher, The American Society of Mechanical Engineers, New York.

resenting the surface to be finished or on a witness line or arrow leading to the surface. The long leg should be on the right-hand side of the symbol as it is read.

A numerical scale for specifying roughness is given in Table 17. These numbers represent root-mean-square average deviation in microinches from a nominal surface, and they vary according to the ASA system of preferred numbers. This is only one of several standards that have been suggested. The roughness designation is combined with the finish symbol as indicated in Fig. 15.4*b*.

Lay may be designated by one of the symbols shown in Table 18, and they are combined with the finish symbol as shown in Fig. 15.4*c*.

The width of roughness is the maximum peak-to-peak spacing of roughness. It may be specified, in inches, adjacent to the lay symbol as indicated in Fig. 15.4*d*.

Waviness is specified by a numeral that expresses its height in thousandths of an inch according to the scale of values given in Table 19. The numeral is combined with the finish symbol by placing it above a bar as shown in Fig. 15.4*e*.

The combination of symbols, illustrated in Fig. 15.4*f*, is a complete specification of geometrical qualities wanted in a finished surface.

Methods of Inspecting Surface Finish

Shop and inspection departments in industry employ two principal methods to evaluate surface finish: (*a*) the surface is compared, visually and by feel, with a standard, and (*b*) roughness is measured with an indicating and/or recording instrument.

Visual and tactile inspection of surface finish

A visual examination is the simplest means of judging the finish on surfaces of any shape, size, or material; but this method alone is unreliable because appearance is not a true indication of roughness. The reliability of this method, however, may be improved by comparing work with graded standards like those shown in Fig. 15.5. The General Electric standard surface specimens in this set are

copies of master surfaces finished by shaping, grinding, and milling; and their roughness is graded in microinches rms to agree with most of the American Standard preferred numbers listed in Table 17. Comparison of work and specimens of this kind by sight and feel is

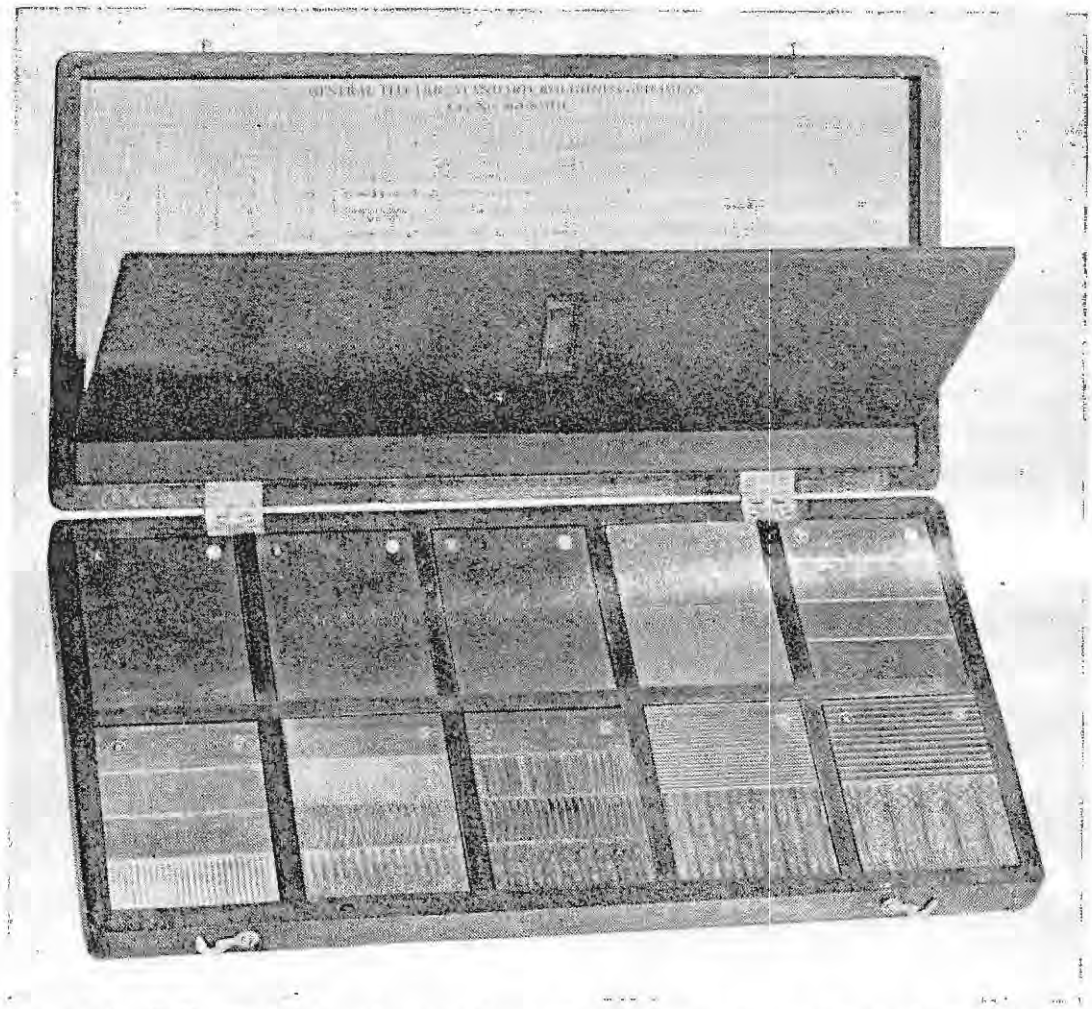


Fig. 15.5 G-E standard surface specimens in case with cover open to show reference chart. *Courtesy of General Electric Company.*

adequate for many requirements. Comparison by feel is accomplished by running the edge of the finger nail, or the tip of the finger, over work and specimen to estimate and compare their roughness. A number of manufacturing companies have produced surface-finish samples and replicas for use in production and inspection.

Although visual comparison may be accomplished with the naked eye, it may be desirable to use a microscope to bring out more de-

tail. A comparison microscope, designed especially for surface inspection, has two stages so that a workpiece and a standard specimen may be mounted in the instrument simultaneously, and viewed as a dual image in the eyepiece.

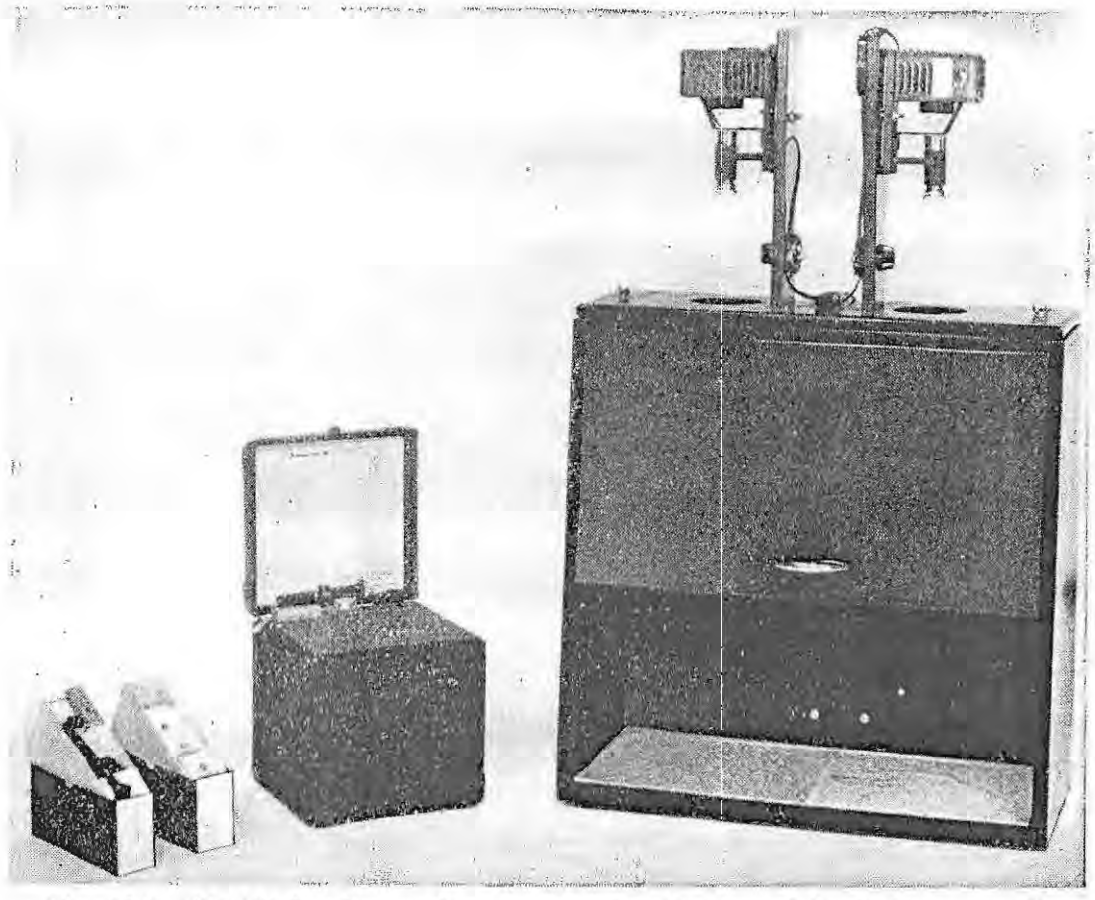


Fig. 15.6 BL-121 Faxfilm surface comparator. *Courtesy of Brush Electronics Co.*

The Faxfilm Surface Comparator and Materials Kit, shown in Fig. 15.6, provide a means of projecting images of surfaces on a screen for examination. The materials for making a Faxfilm consist of a clear plastic film or ribbon, plastic solvent, and mounting frames. A Faxfilm is made by cutting ribbon to the required length, applying solvent to either the ribbon or surface of a workpiece, and pressing the ribbon on the work. After about 45 sec, the ribbon may be removed and mounted in a frame. This process produces a reverse replica of the surface that may be projected to show a magnified image which may be viewed by a group, if desired. The Surface Comparator has two microprojectors so that replicas of a

work surface and a standard surface may be projected simultaneously to permit comparison with each other. This unit gives a magnification of 30 diameters when images are projected onto screens in the bottom of the case. Greater magnification may be obtained by turning the projectors 90 deg and projecting the images horizontally onto a wall or screen. A permanent record of inspection may be kept by filing Faxfilm or by projecting the Faxfilm image onto a photographic plate which may be developed, printed in the regular way, and filed.

Instrument inspection of surface finish

Indicating and recording instruments that measure roughness in microinches rms are used to check comparison standards for accuracy and to measure work directly as a means of controlling surface finish. This measurement is accomplished by moving a diamond tracer point or stylus over the work. During this movement, the tracer point is displaced by the minute ridges and valleys on the surface, and its displacement is amplified and registered on a meter or chart for reading and analysis.

Profilometer[1]

The Profilometer, illustrated in Fig. 15.7, is a tracer instrument that consists of two principal units; a tracer, shown in contact with the shaft which is being inspected, and an Amplimeter, shown at the top left in the picture. Shown also in this illustration are a Mototrace at the bottom left, and a reading recorder at the top right of the picture.

The Profilometer tracer contains a conically shaped diamond tracer point that is used to explore the surfaces which are inspected. The diamond mounting is screwed into a bearing supported tube that terminates in a coil of wire, and the coil is located in the field of a permanent magnet so that movement of the coil will induce a voltage. As the tracer is moved over a surface, irregularities cause

[1] Information in this section is adapted from literature furnished through courtesy of Micrometrical Manufacturing Company.

the tracer point to vibrate; the vibration is transmitted to the coil in the magnetic field, and the induced voltage is amplified and measured with the Amplimeter. Tracers of different designs are available for measuring surfaces of practically any shape, size, and location.

Fig. 15.7 Profilometer in use showing tracer, Mototrace, amplimeter, and reading recorder units. *Courtesy of Micrometrical Manufacturing Co.*

The Amplimeter amplifies the voltage produced by the tracer so that it actuates the meter on the panel. The meter reading represents the surface roughness in microinches rms of the part being inspected. If the surface is uniform in character, a steady reading will be obtained; but if it is not, average variations may be estimated from the meter's fluctuations. A switch provides six full-scale meter readings of 3, 10, 30, 100, 300, and 1,000 μin., and an additional full scale range of 1 μin. can be provided.

Some tracers may be operated manually, and all can be operated mechanically. Manual tracing is desirable in many cases because of

its speed, convenience, and ability to inspect hard-to-reach and large surfaces. The Profilometer Stiffarm, shown in Fig. 15.8, may be used with manual tracing to reach into deep holes and recesses. And its use in tracing very smooth surfaces contributes to accuracy because the tracer can seat itself of its own weight and because the tracer can be held more lightly, thus permitting steadier motion with less vibration.

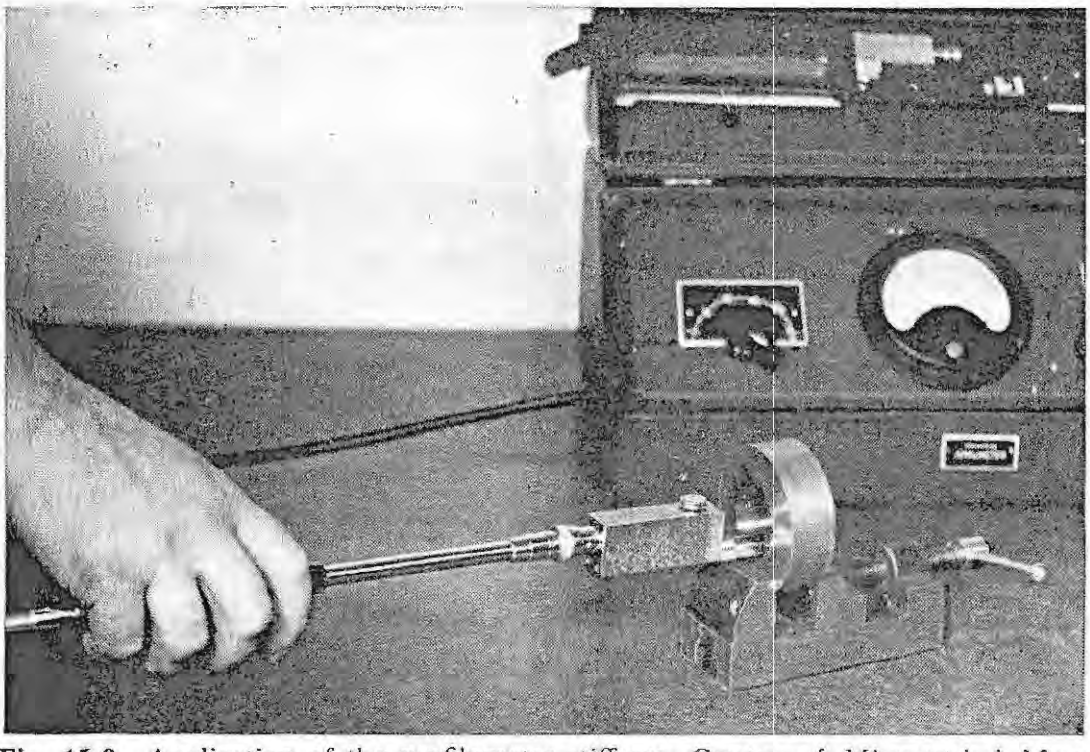


Fig. 15.8 Application of the profilometer stiffarm. *Courtesy of Micrometrical Manufacturing Co.*

Tracers that are operated manually, and with the Mototrace to be described later, are equipped with Skidmounts and skids of various designs which adapt them for application to different sizes and shapes of work. Two or three skids, depending on the design, rest on the work during inspection operations and provide a reference level for measurements.

Mechanical tracing is done with motor-driven mechanisms that support and move the tracer over the work. This method is recommended for many applications because the steady tracing speed and smooth reversals, which are difficult to obtain with manual operation, result in accurate readings. Mechanical tracing is de-

sirable or necessary for repetitive measurements and for measurements that also require a circular tracing motion.

The Mototrace, one of the units shown in Fig. 15.7, is a motor-driven mechanism that may be used to move skid-type tracers along the surface being measured with a stroke which may be varied from

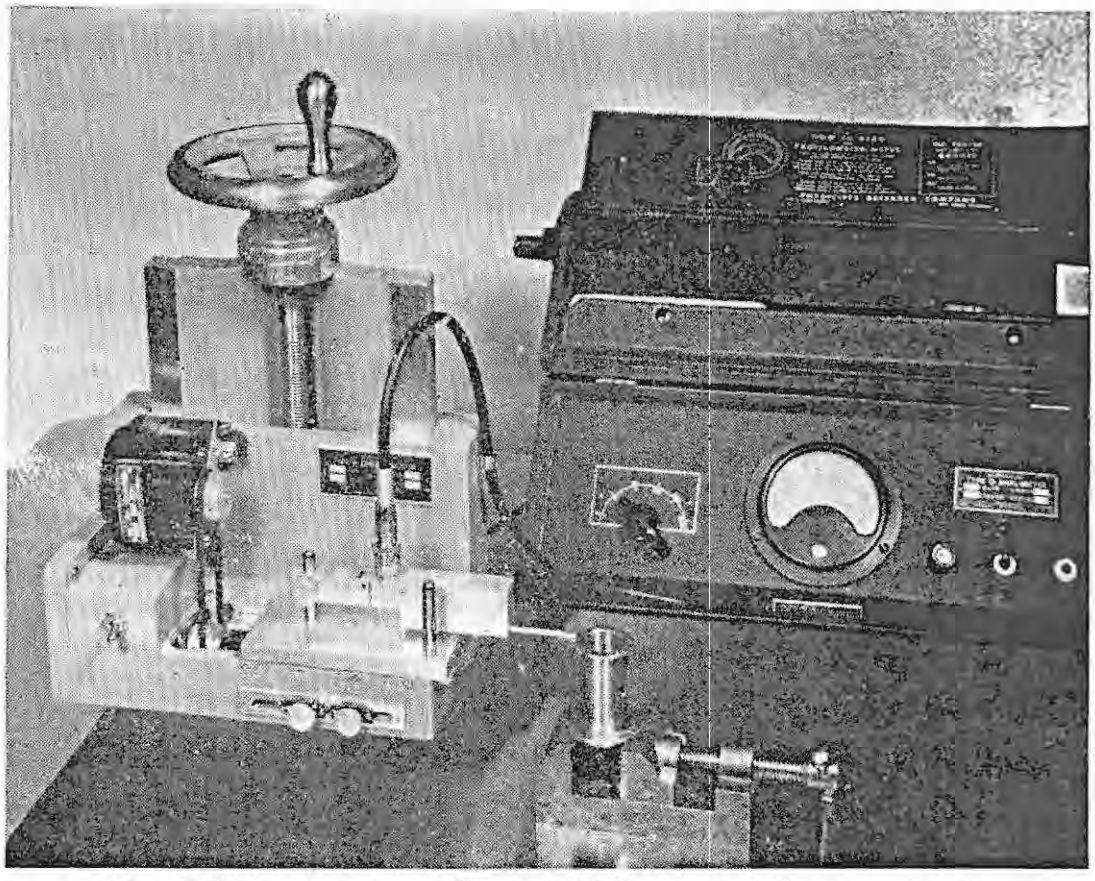


Fig. 15.9 Linear pilotor. *Courtesy of Micrometrical Manufacturing Co.*

1/16 to 2 3/4 in. The tracer is attached to a vertical post on the Mototrace by a Linkarm.

The Linear Pilotor, shown in Fig. 15.9 consists of a vertical column mounted on a rigid base. The column carries a saddle which may be adjusted vertically by means of a handwheel at the top; and the saddle carries a motor-driven reciprocating slide on which either a skidless tracer or a skid-type tracer and Linkarm may be mounted. The skidless tracer, shown in the illustration, is designed for use in narrow slots, grooves, and similar applications; and it must be supported and moved by the Linear Pilotor because it lacks skids to support and guide it on the surface of the work.

The Rotary Pilotor, illustrated in Fig. 15.10, provides the circular tracing motion needed for measuring surface roughness around internal and external surfaces of rotation such as cylinders, spheres, and toroids; across grooves of circular cross section such as ball-bearing raceways; and around the top of circular horizontal sur-

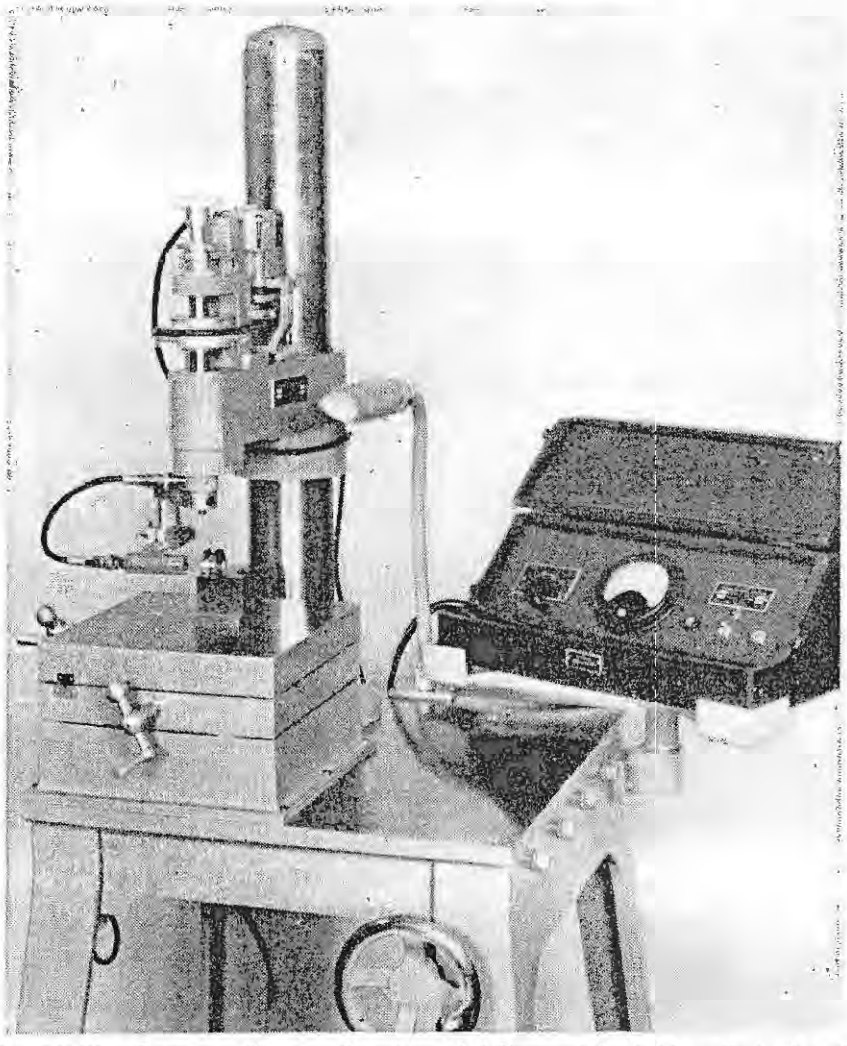


Fig. 15.10 Rotary pilotor. *Courtesy of Micrometrical Manufacturing Co.*

faces such as rings, grooves, and bosses. Parts of the Rotary Pilotor consist of: (*a*) a vertical spindle, for rotating a tracer horizontally in a circular path; (*b*) a spindle-drive motor; (*c*) various tracers and tracer adapters, for measuring internal and external surfaces on a wide variety of parts; (*d*) a saddle, mounted on a column, providing vertical adjustment of the spindle and its drive unit for measuring surfaces at different heights; (*e*) a table with longitudinal and trans-

verse adjustments, for holding and locating parts to be measured; and (*f*) a floor stand to hold the foregoing parts and a Profilometer Amplimeter.

The Profilometer reading recorder, shown at the top right in Fig. 15.7, provides a continuous chart record of Profilometer meter

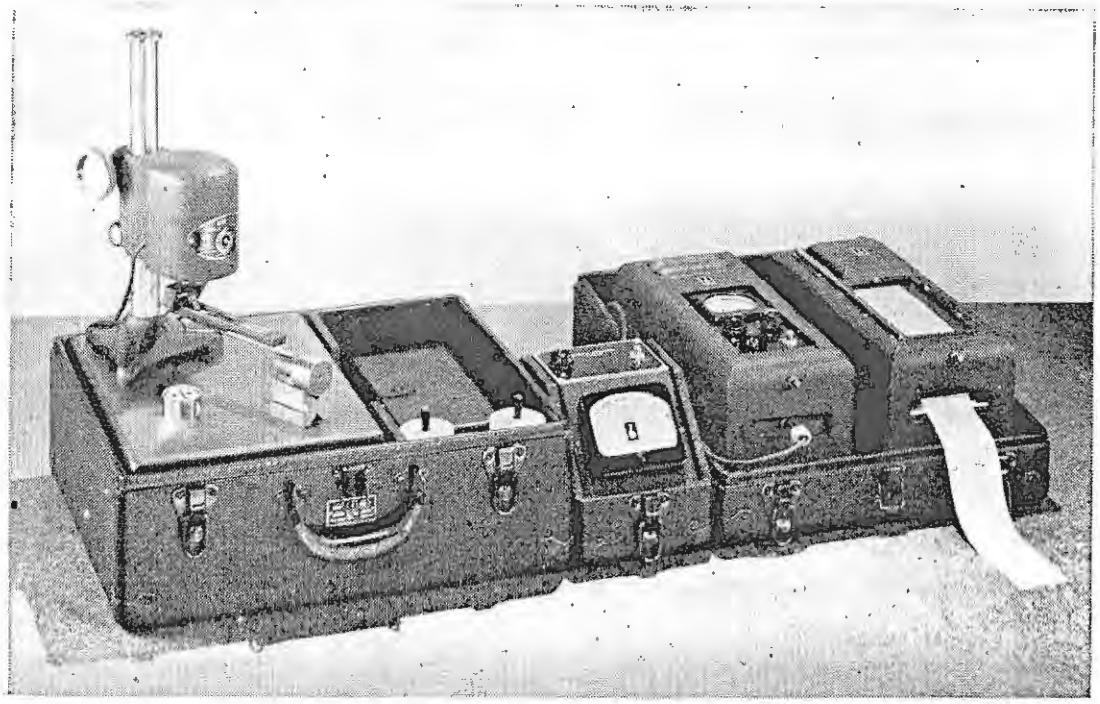


Fig. 15.11 Surface analyzer, Model BL-103. *Courtesy of Brush Electronics Co.*

readings of roughness height in microinches rms. Charts are useful (*a*) for providing a permanent record of readings which may be filed or furnished to customers with parts; (*b*) they facilitate close determination of point-to-point variations in surface roughness, clearly locating the rougher or smoother portions of the work; (*c*) they show the range of surface roughness; and (*d*) it is easy to obtain a single roughness rating from the chart.

Surface Analyzer[1]

The Surface Analyzer, shown in Fig. 15.11, is a tracer instrument that is designed to explore and chart surface finishes. Its principal parts are, reading from left to right in the illustration: (*a*)

[1] Information in this section is adapted from literature furnished by Brush Electronics Co.

a drive head and pickup arm, (*b*) a "RMS" meter, (*c*) a calibrating amplifier, and (*d*) a direct-inking oscillograph. Accessory equipment consists of a surface plate on which the drive-head assembly and work are mounted, V blocks for supporting the work, a calibrating standard, and chart paper and ink. All parts and accessories come packed in two carrying cases with removable covers.

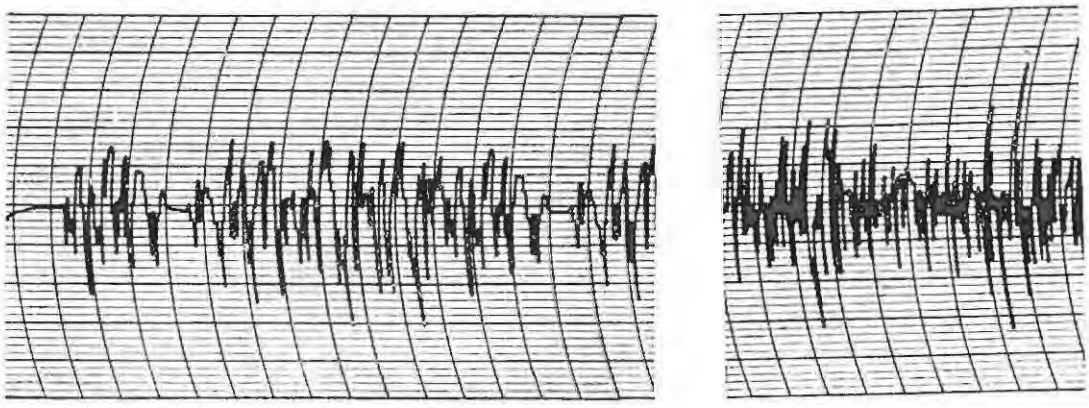
The standard drive head consists of a motor, gear train, and a cam that imparts a $\frac{1}{16}$-in. horizontal reciprocating motion to a drive shaft and the pickup arm. One stroke cycle of the pickup arm requires 10 sec, which produces a tracing speed of 0.0125 in. per sec. The drive-head unit, which is mounted on a tripod stand and column, can be adjusted vertically by a rack-and-pinion assembly. A special drive head is available for analyzing surfaces of over 100 μin. rms roughness.

The pickup arm houses a piezoelectric crystal in its outer end, and the crystal is connected with a diamond stylus on the tip of the pickup arm through a system of levers. An adjustable positioning shoe in back of the stylus rests on the work to support the free weight of the pickup arm and to provide a reference level for the stylus. When the stylus is reciprocated over the work, surface irregularities cause it to move vertically. Movement of the stylus is transmitted to the crystal. This flexes or bends the crystal and generates a voltage the magnitude of which depends on the travel of the stylus, and the polarity of which depends on the direction. Special pickup arms are available for exploring surfaces that are difficult to reach with the standard arm.

The calibrating amplifier receives the voltage generated by the crystal pickup, magnifies it, and delivers it to the direct-inking oscillograph. A six-step "attenuator," or sensitivity control, is adjustable for different degrees of roughness on analyzed surfaces; and a gain control provides a fine adjustment for the amplification.

The direct-inking oscillograph makes a chart record of surface irregularities, traced by the stylus and magnified by the amplifier, on a moving strip chart in the form shown by Figs. 15.12*a* and 15.12*b*. A motor-driven chart-feed mechanism in this unit provides

for the selection of any one of three rates of feed which give longitudinal magnification of 16, 80, or 400 to 1. The pen fluctuates across the paper according to the direction and magnitude of the movement of the stylus, and the resulting trace is a magnified profile of the surface being explored.



a *b*

Fig. 15.12 Sample charts from Surface Analyzer. Sample (*a*) was taken after a coarse grind followed by a fine grind on a stainless-steel specimen. Deep valleys of the coarse grind remain, but the peaks have been partially removed. The rms value is about 42 μin., and the maximum peak-to-valley is 240 μin. (peak 85, valley 155). Each fine horizontal line equals 10 μin., and a horizontal chart division is 20. The rms value of chart (*b*) is approximately 42 μin. also, but the maximum peak-to-valley range is 350 μin. (peak 160, valley 150). *Courtesy of The Brush Development Co.*

The "RMS" meter is an accessory which may be used with the Surface Analyzer to give a visual reading of surface roughness. It may be employed with chart recording, or separately if the refinement of the chart profile is not required. With the amplifier "attenuator" set on the 0.001 tap, the upper dial on the meter reads directly in microinches rms, and its full scale reading is 10 μin. With it on the 0.010 tap, readings are multiplied by 10, etc. A push-button control increases the sensitivity of the meter 3⅓ times, and the bottom scale is read. With the attenuator set on the 0.001 tap, each division will read 3 μin., etc.

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QUESTIONS

1. The elements of surface finish consist of: (*a*) surface flaws, (*b*) waviness, and (*c*) roughness. Define each of these terms.
2. Draw a horizontal line to represent a finished surface. Above it, draw a symbol to indicate the surface to be finished with (*a*) a roughness height value of 50 μin. rms; (*b*) a waviness height value of 0.002 in.; (*c*) the lay of the surface pattern parallel to the boundary line of the surface indicated by the symbol; and (*d*) a roughness width value of 0.005 in.
3. Name two instruments that are designed to measure surface finish.
4. Describe another method that may be used to evaluate surface finish.

16

INSPECTION TO REVEAL SURFACE AND SUBSURFACE FLAWS

Surface and subsurface flaws, invisible to the eye, are frequent causes of failure of manufactured products. In some cases, the flaws are the result of defects in raw materials, faulty product design, or improper processing; and in other cases, they are the result of repeated stresses imposed on parts of equipment in service. In either event, the flaws should be revealed by inspection that is conducted to discover and reject defective materials and products as early in the manufacturing process as possible; to gather data which will lead to improved raw materials, designs, and manufacturing processes; or to retire defective parts of equipment before they can fail in service. Tests to reveal such flaws must be adaptable to routine examination of raw materials and products in jobbing shops and mass-production manufacturing plants, to periodic inspection in service work, and they must be nondestructive.

A number of nondestructive tests for revealing invisible surface and subsurface flaws in magnetic metals and parts, in nonmagnetic metals and products, and in nonmetals have been developed for use in inspection. Among the best known are several variations of magnetic-particle inspection, fluorescent penetrant inspection, electrified-particle inspection, filtered-particle inspection, ultrasonic inspection, and radiographic inspection.

Magnetic-particle Inspection: Magnaflux,[1] Magnaglo,[2] and Duovec[3] Processes

Magnetic-particle inspection is a process that is employed to reveal invisible surface and subsurface flaws in ferromagnetic materials, principally irons and steels, by magnetizing the part being inspected and applying finely divided ferromagnetic particles to its surface. If there is a crack or a nonmetallic inclusion at or near the surface of the induced magnet, lines of force in the B magnetic field, that surround and flow through the magnet in closed circuits, will be broken. Wherever a circuit is broken, a local leakage field will be produced. That is, north and south poles appear, one on each side of the flaw, and magnetic lines of force flow out of and back into the magnet across the defect. Ferromagnetic particles applied to the work in the vicinity of a local leakage field will be magnetized by induction; they will be attracted to the poles; and they will move into positions which reveal the location, extent, and character of the defect. Cracks as much as 2 in. under the surface, and surface cracks as little as 0.002 in. deep will be revealed under favorable circumstances. A trained inspector is able to distinguish between such different kinds of defects as cracks, seams, roll marks, scratches, and checks; and he is able to estimate their size, depth, and relative importance.

Work to be inspected by the magnetic-particle process may be magnetized in several ways:

1. *Circular magnetization:* In circular magnetization, an electric current is passed from end to end either through the work itself or through a central conductor such as a rod or cable through a hollow specimen. The lines of force are concentric with the center line of the conductor; the magnetic field is contained almost entirely within the work; and there is little leakage except where there is a flaw, or change of section, at an angle to the lines of force. Circular

[1, 2, 3] Magnaflux, Magnaglo, and Duovec are registered trade-marks applied by the Magnaflux Corporation to its equipment and materials for magnetic-particle and fluorescent magnetic-particle inspection.

magnetization will locate practically any defect that may be discovered by magnetic-particle inspection.

2. *Longitudinal magnetization:* In longitudinal magnetization, current is passed through a helical conductor or solenoid that surrounds the work. A magnetic field is induced in the work by lines of force that are concentric to the windings of the solenoid. The resultant field in the work is similar to that of a bar magnet from which lines of force emerge at its north pole, pass through the air, enter at the south pole, and flow back through the magnet to complete the circuit. This kind of magnetization is useful for locating transverse flaws such as fatigue cracks in work. Longitudinal magnetization may be induced in work such as large shafts, large castings, and similar objects by wrapping a current-carrying cable around it.

3. *Swinging-field magnetization:*[1] In swinging-field magnetization, circular and longitudinal magnetizing shots are applied simultaneously while a bath containing ferromagnetic particles is directed onto the work. The resultant magnetic field swings through an angle of more than 90 deg so that both longitudinal and transverse defects will show in one operation.

4. *Circular magnetization by local contact:* Very large castings and heavy tank or casting weldments are usually locally magnetized by making contact with prods along 6 to 8 in. of the weld or casting. Prods are cable attached to a portable magnetic unit; and high-amperage, low-voltage current (800 to 4000 amp) is passed through the work between the prods to establish high-level local circular magnetization within the work. This magnetization with half-wave direct current is the most favorable to locate deep-seated cracks and similar defects. Changing prod location allows magnetization in any direction or location desired.

5. *Fields induced by electromagnets:* Magnetic fields may be induced in work by placing the workpiece across the poles of a magnetic yoke or by using an electromagnet having a U-shaped core. The

[1] The name "Duovec" is applied to equipment to induce swinging-field magnetization of work and its inspection. It is produced by Magnaflux Corporation.

work, thereby, completes a circuit which permits the magnetic flux to return through the metal instead of air.

Two electromagnets having straight cores may be used to induce a magnetic field in a plate or bar by placing the north pole of one and the south pole of the other on the work, or two like poles may be employed in some cases. The field produced by the two magnets is similar to that caused by a magnetic yoke, except that there is no metallic return. This return may be obtained easily by placing an iron bar to close the circuit. Magnetization with electromagnets is useful at times for inspecting welds in large plates, but the high leakage at applied poles makes its use difficult.

Direct current, alternating current, or rectified alternating current may be employed to induce the magnetic field in workpieces for magnetic-particle inspection. Direct current is used principally for applications where it is important to detect subsurface flaws and to inspect welds in thick sections. The use of alternating current is an advantage where surface flaws only need to be revealed because this kind of current tends to flow along the surface of the conductor. A fuller discussion of the best kind of electric current and its characteristics for different applications is beyond the scope of this article.

Two methods of applying the magnetizing current and inspection medium, with respect to time and sequence, may be employed. In the continuous method, the current and ferromagnetic particles are applied to the work simultaneously; but in the residual method, the current is applied first and the particles are applied afterward. The latter (residual) can only be used with magnetically retentive work materials.

Ferromagnetic particles should be of a quality and size suited to reveal the defects which are sought. The Magnaflux Corporation produces controlled particles in the form of gray, black, and red powders for application by the dry method; and as black, red, and fluorescent pastes for use by the wet method.

Ways that may be employed to apply ferromagnetic powders by the dry method include the use of hand shakers, spray bulbs, shak-

ing screens, blowing in an air stream, and rolling or tumbling parts in the powders. After powder has been applied, the part being inspected should be gently blown or tapped to remove excess and to assist the particles to arrange themselves at defects if any are present. The dry method is most useful for inspecting unmachined castings and forgings, large and heavy equipment, and welds.

In applying ferromagnetic pastes by the wet method, the particles are suspended in a light oil. The fluid mixture may be sprayed or hosed on the work being inspected, or parts may be dipped. The wet method is suited to inspecting machined castings and forgings. It is also widely used to inspect unfinished parts.

Magnaglo is a fluorescent Magnaflux paste. It is applied by the wet method in the same ways as other Magnaflux pastes except that parts are examined under black light, and the indications appear as bright greenish-yellow fluorescent lines which quickly attract the inspector's eye.

Magnaflux indications may be recorded by photography, or they may be preserved by transfer to notebooks with cellophane tape or stripping lacquer.

After magnetic-particle inspection, parts must be demagnetized and cleaned with more or less care, depending on the materials of which they are made and the uses to which they will be put.

Magnaflux inspection equipment is made in a number of styles and sizes. Some general-purpose units are designed to inspect as wide a variety of work as possible in manufacturing-plant applications; others are engineered to inspect a limited range of work in mass production; and still others are portable for inspecting tanks, boilers, and similar work, and for field inspection.

A general-purpose Magnaflux unit equipped for use with Magnaglo is shown in Fig. 16.1. This is the general form of units for magnetizing work in the horizontal position. Parts to be magnetized rest on two fiber or Bakelite shelves that are attached to two lead-faced copper contact plates. One plate is supported on a fixed head at the left in the illustration, and the other is on an adjustable head at the right. Work to be magnetized by the circular method is

clamped between the heads by air cylinder, and current is passed through it. The duration of current flow is regulated by a pneumatic timer. Either the continuous or residual method of magnetizing the work and applying the indicating fluid may be employed. The in-

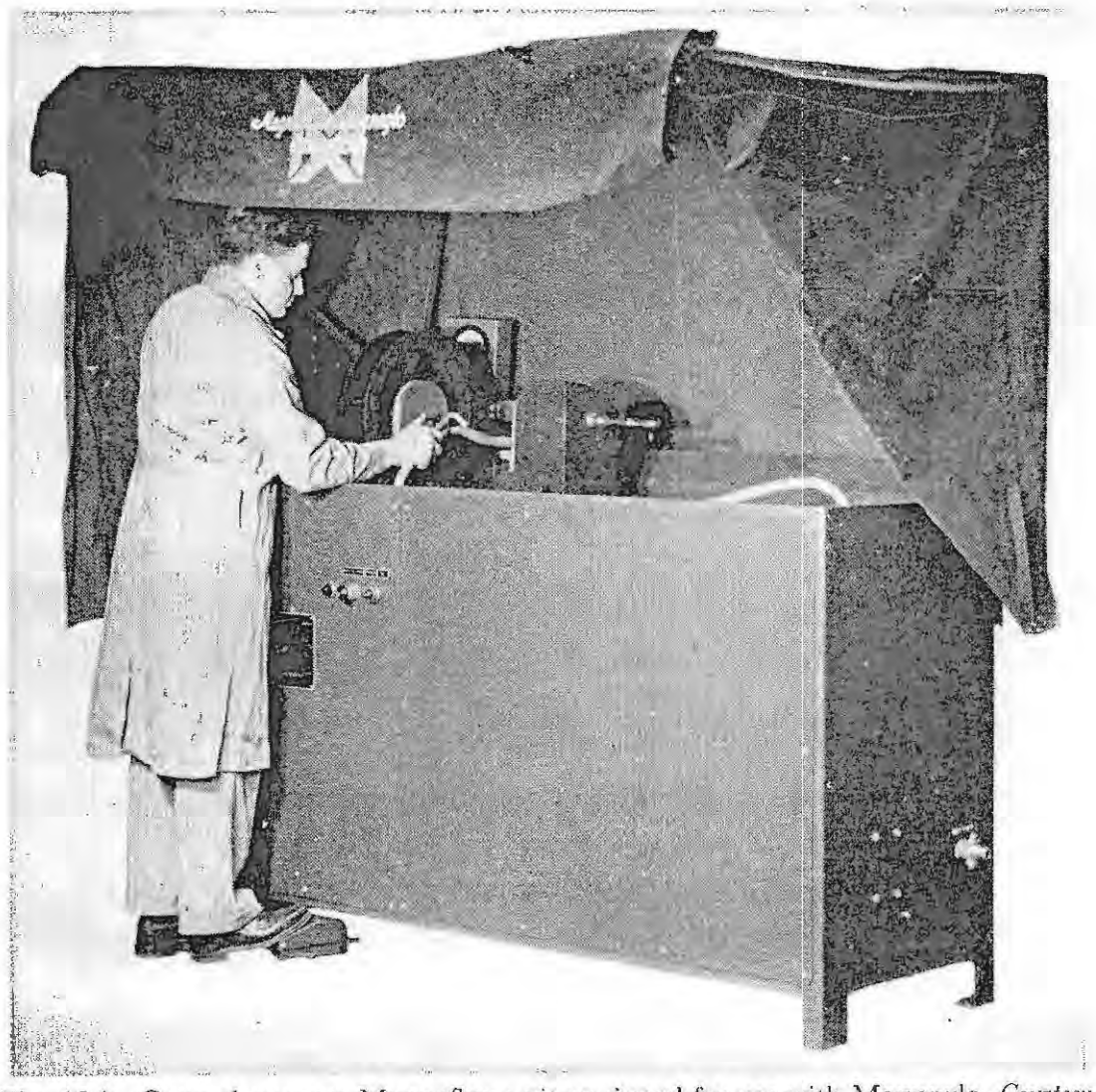

Fig. 16.1 General-purpose Magnaflux unit equipped for use with Magnaglo. *Courtesy of Magnaflux Corporation.*

dicating fluid is contained in a circulating system that consists of a reservoir, motor-driven pump, hose and nozzle, grill table top, drain, and screen to remove foreign particles. When work is to be magnetized longitudinally, the coil shown at the fixed head is moved along the bed and around the part.

The portable Magnaflux unit, shown in Fig. 16.2, is a type that

is widely used in refinery, heavy casting and heavy weldment inspection. In this illustration, it is being employed to inspect a pipe weld in a refinery. Alternating current or half-wave rectified alternating current may be used with this unit to magnetize work, and

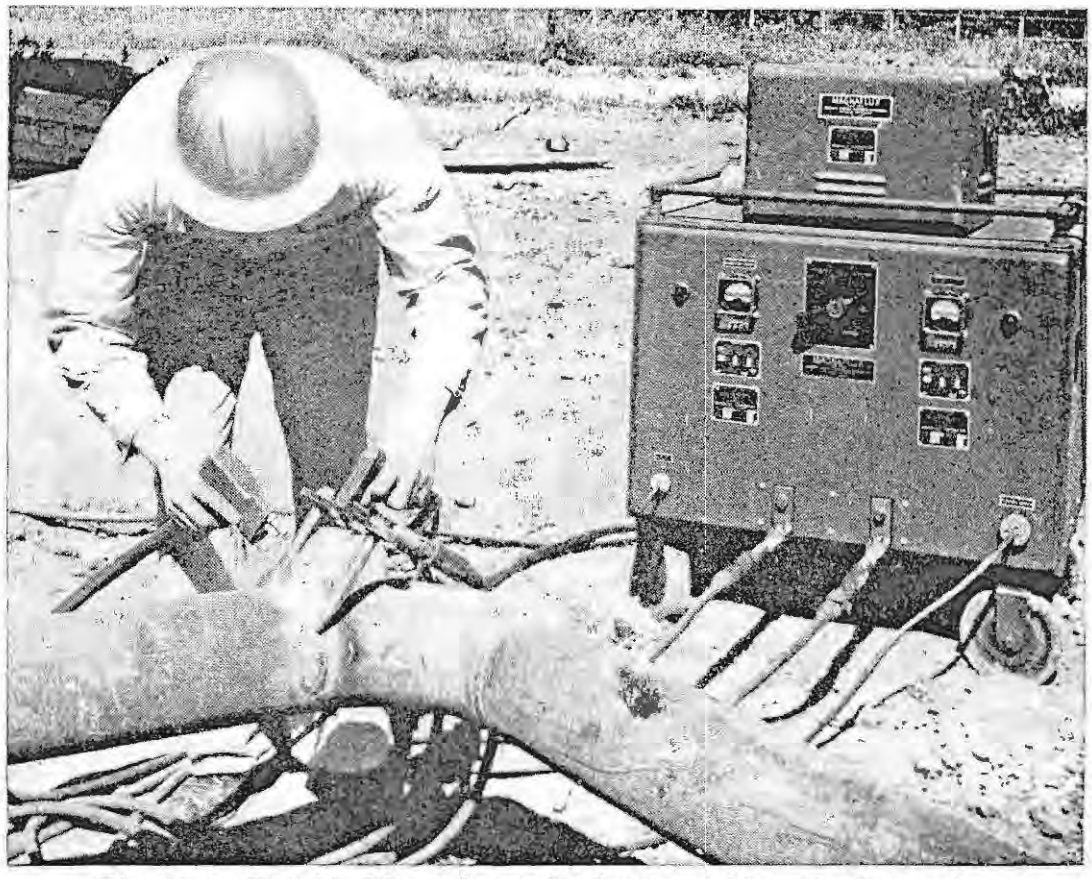

Fig. 16.2 Portable Magnaflux unit. *Courtesy of Magnaflux Corporation.*

current is conducted and applied to the work by means of a heavy cable and prod-type contacts. A blower for applying dry powder is shown on top of the Magnaflux unit. Powder is blown onto the work with a gun that contains a built-in light to illuminate the working area. When the stream of powder is shut off, a stream of air is substituted to blow excess powder off of the work. A few portable Magnaflux units are battery operated to give them the greatest possible amount of mobility.

A special, automatic, high-speed Magnaflux-Magnaglo unit is shown in Fig. 16.3. This is one of numerous units that are in operation in high-volume production industries to inspect castings and

forgings in the rough state, to prevent defective parts from getting into production and service, and to control primary processes by locating defects as early as possible.

Typical Magnaflux black-paste indications revealing grinding

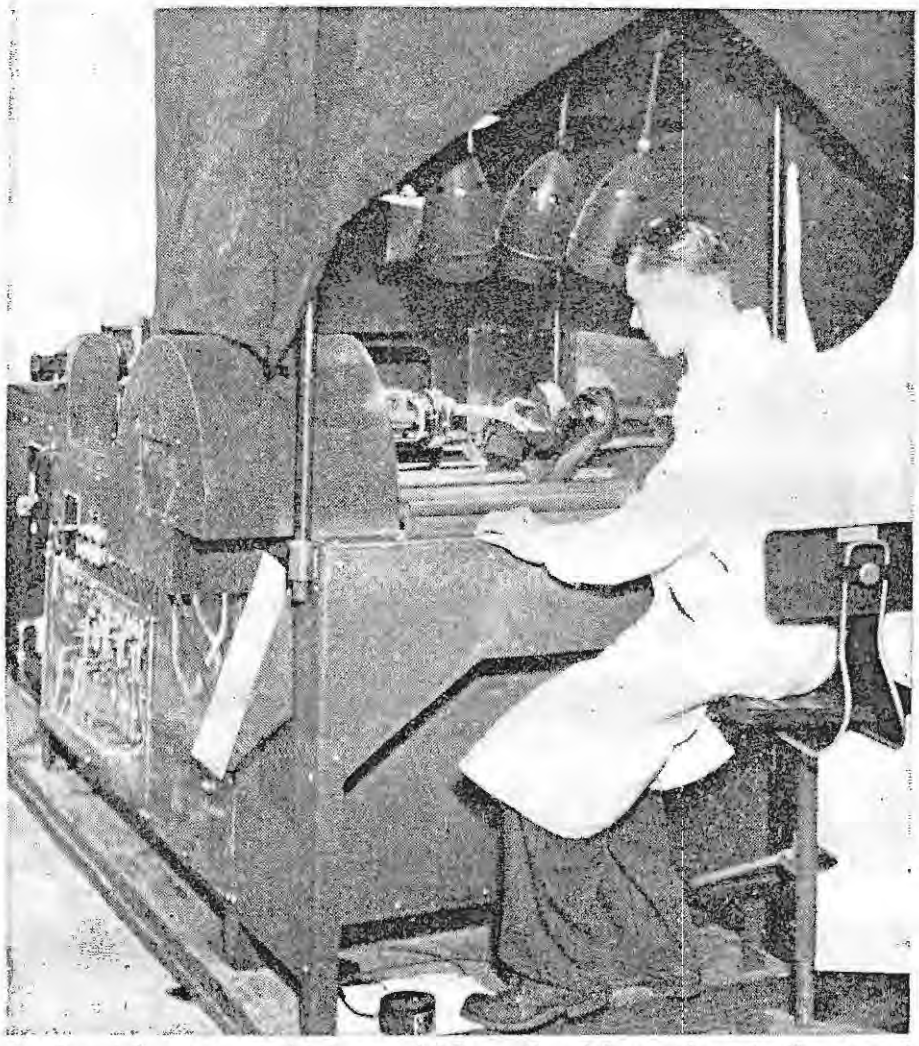

Fig. 16.3 Special automatic high-speed Magnaflux-Magnaglo unit. *Courtesy of Magnaflux Corporation.*

checks in a finished truck kingpin are illustrated in Fig. 16.4. A Magnaflux dry-powder indication showing a surface crack in a steel weld is illustrated in Fig. 16.5.

Magnaglo glowing fluorescent indications, photographed under black light, that show fatigue cracks in a truck front-wheel spindle, which were located by Magnaglo inspection during overhaul, are illustrated in Fig. 16.6.

Fluorescent Penetrant Inspection: Zyglo[1] Process

Zyglo fluorescent penetrant inspection is a nondestructive testing method that may be employed to reveal defects in work which open on its surface. In applying this process, it is necessary to clean parts

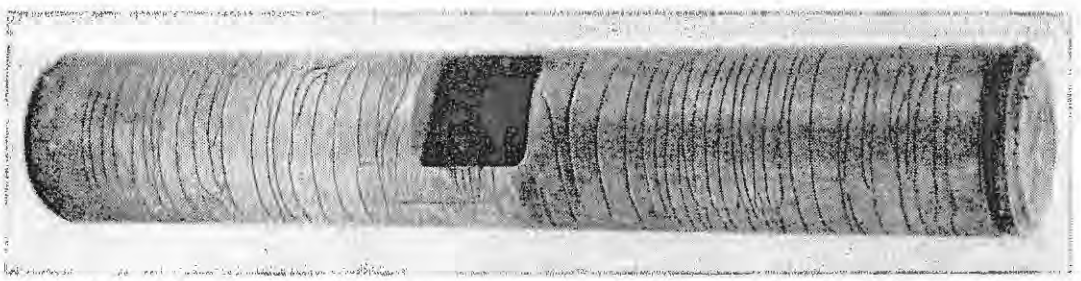

Fig. 16.4 Magnaflux black-paste indications. *Courtesy of Magnaflux Corporation.*

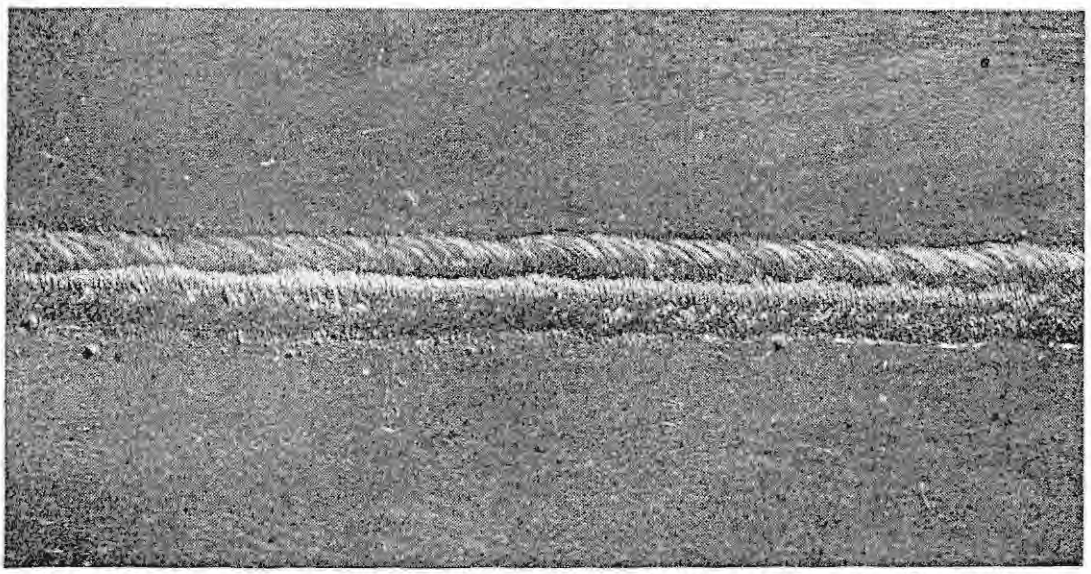

Fig. 16.5 Magnaflux dry-powder indication. *Courtesy of Magnaflux Corporation.*

of foreign matter that clog the surface openings. Following that, the fluorescent liquid penetrant may be applied by brushing, spraying, or dipping. Next, excess fluid is allowed to drain off during a time interval which is required to allow the penetrant to seep into defects. This interval, that may vary from a few minutes to several hours, usually lasts from 5 to 15 min. At the end of this period, parts are rinsed with a water spray and dried by wiping, with an air

[1] Zyglo is a registered trade-mark of the Magnaflux Corporation applied to its equipment and materials for fluorescent penetrant inspection.

blower, or in an oven. Rinsing should be done under black light to assure removal of all fluorescent material from the surface of the work. After parts have been dried: (*a*) they are dusted with a developing powder that draws the penetrant out of flaws to the surface

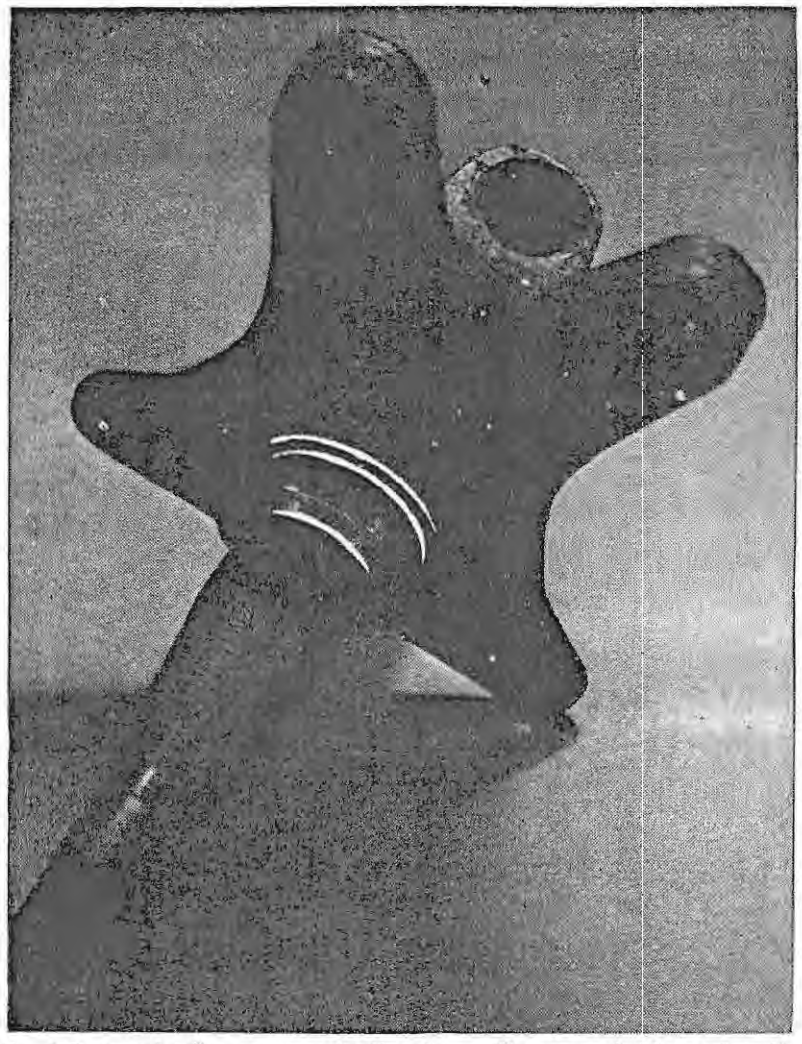

Fig. 16.6 Magnaglo fluorescent indications. *Courtesy of Magnaflux Corporation.*

of the work; or (*b*) they are first dipped in a water suspension colloid of a developer and dried. Both processes increase the brilliance of the fluorescent indications when the parts are inspected under black light in a darkened booth. A general-purpose Zyglo unit for sampling or 100 per cent inspection of parts up to 12 in. in diameter is shown in Fig. 16.7; and a Zyglo fluorescent indication, glowing under black light and showing a shrinkage crack pattern in a cast-aluminum motor housing, is illustrated in Fig. 16.8.

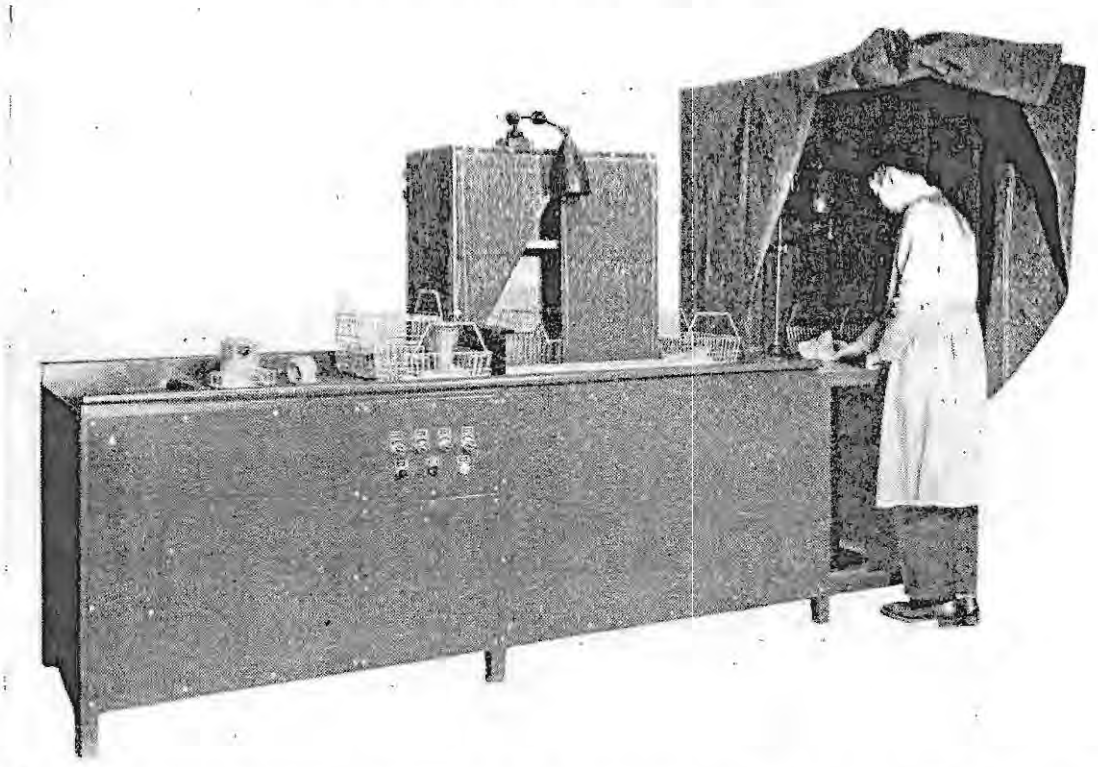

Fig. 16.7 General-purpose Zyglo unit for inspecting parts up to 12 in. in diameter. *Courtesy of Magnaflux Corporation.*

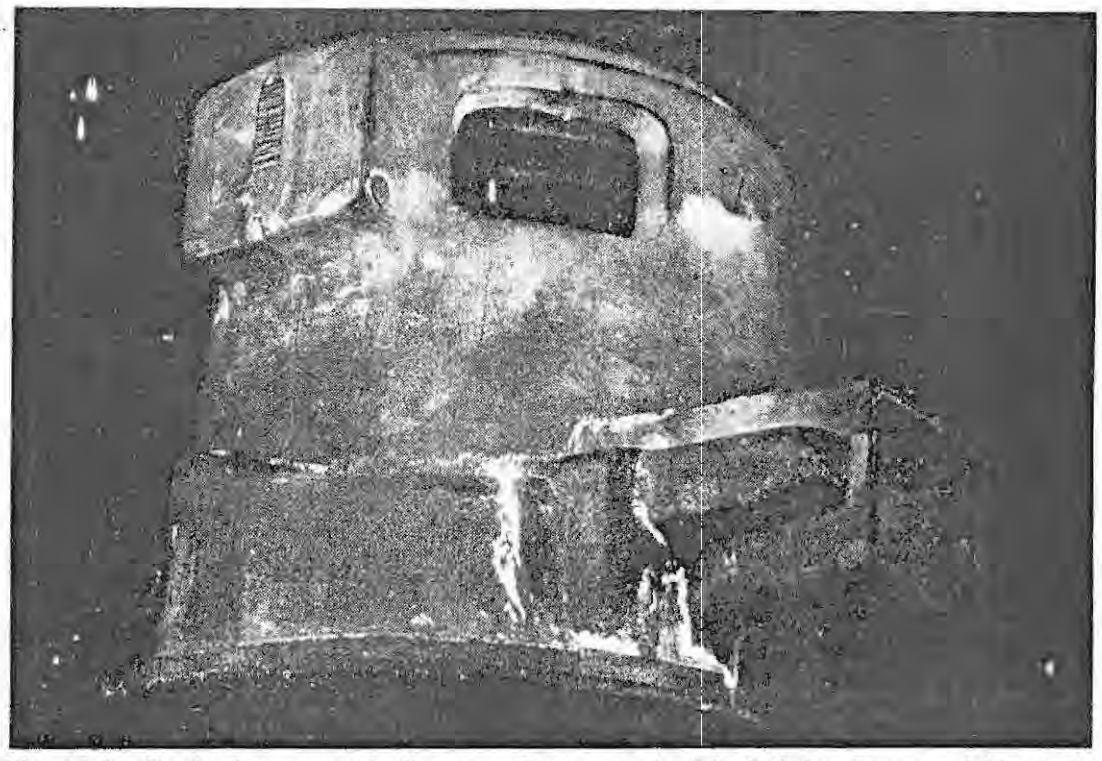

Fig. 16.8 Zyglo fluorescent indication glowing under black light. *Courtesy of Magnaflux Corporation.*

Electrified-particle Inspection: Statiflux[1] Process

Electrified-particle inspection is a nondestructive method of testing nonconducting products such as ceramics, porcelain enamels, glass, glazed china, and plastics to locate defects that open on the

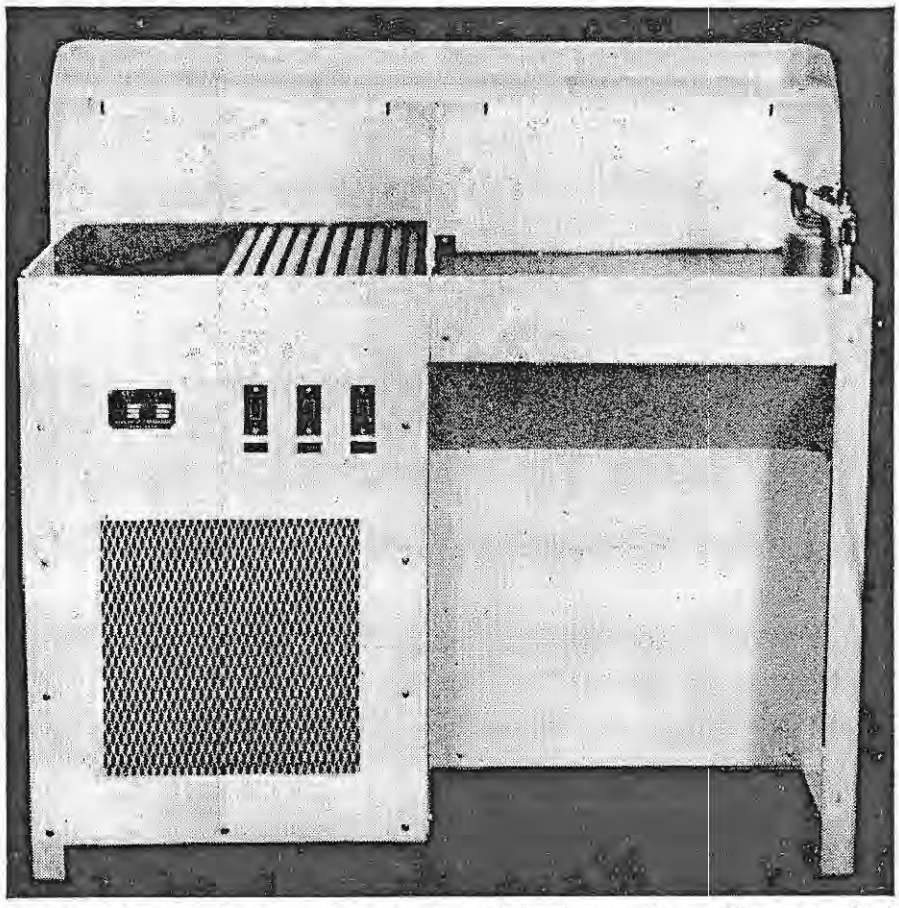

Fig. 16.9 Statiflux unit for electrified-particle inspection. *Courtesy of Magnaflux Corporation.*

surface. In applying this process, the part to be inspected is covered with a special penetrant which conditions the flaws to attract the indicating medium. Next, the work is dried by wiping, by air blast, or in warm air. Then particles of powder, suitably colored to provide contrast, are blown onto the work with a Statiflux gun which induces electrostatic charges on them. As the charged particles are blown onto the surface of the work, they are electrically attracted to cracks or pores where they build up to produce visible indications of the defects. A small Statiflux unit, used for sampling control in-

[1] Statiflux is the registered trade-mark of Magnaflux Corporation applied to its equipment and materials for electrified-particle inspection.

spection to find cracks in bottles, small porcelain-enamel products, fired insulators, and similar parts made of nonconducting materials, is shown in Fig. 16.9. The Statiflux gun may be used separately on large bodies. Statiflux-powder indications on normally invisible

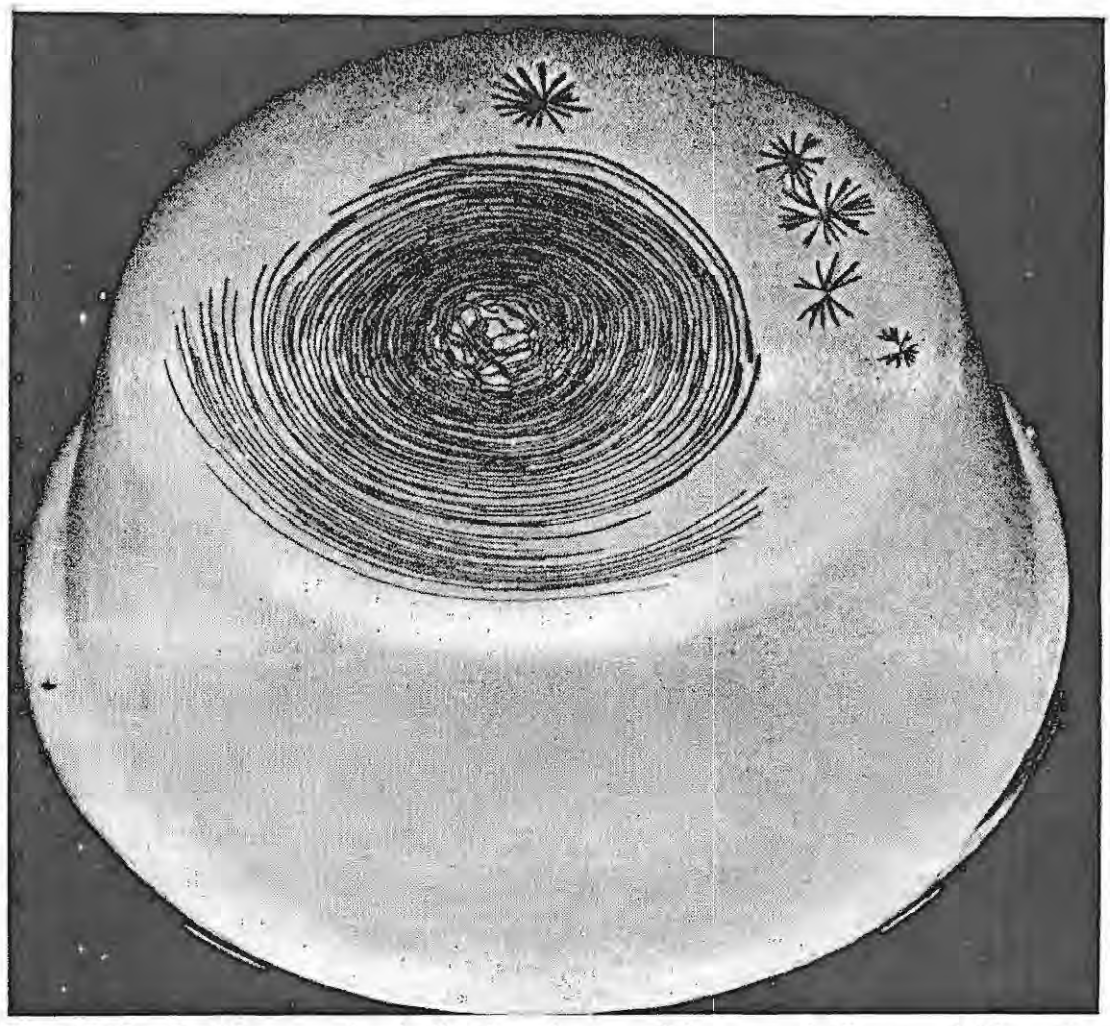

Fig. 16.10 Statiflux powder indications in porcelain enamel. *Courtesy of Magnaflux Corporation.*

cracks in porcelain enamel are illustrated in Fig. 16.10. Star-shaped impact cracks and a large heat-crack pattern are shown on this test pan.

Filtered-particle Inspection: Partek[1] Processes

Filtered-particle inspection is a process that may be used to locate cracks in porous articles such as unfired clayware, dinnerware, sani-

[1] Partek is a registered trade name of Magnaflux Corporation applied to materials and equipment for use with filtered-particle-inspection methods.

tary ware, unsintered powdered-metal compacts, and other porous bodies. Inspection is performed by dipping the work into a liquid containing fine particles dispersed through it or by spraying the liquid onto the object. A porous material absorbs a liquid when wet

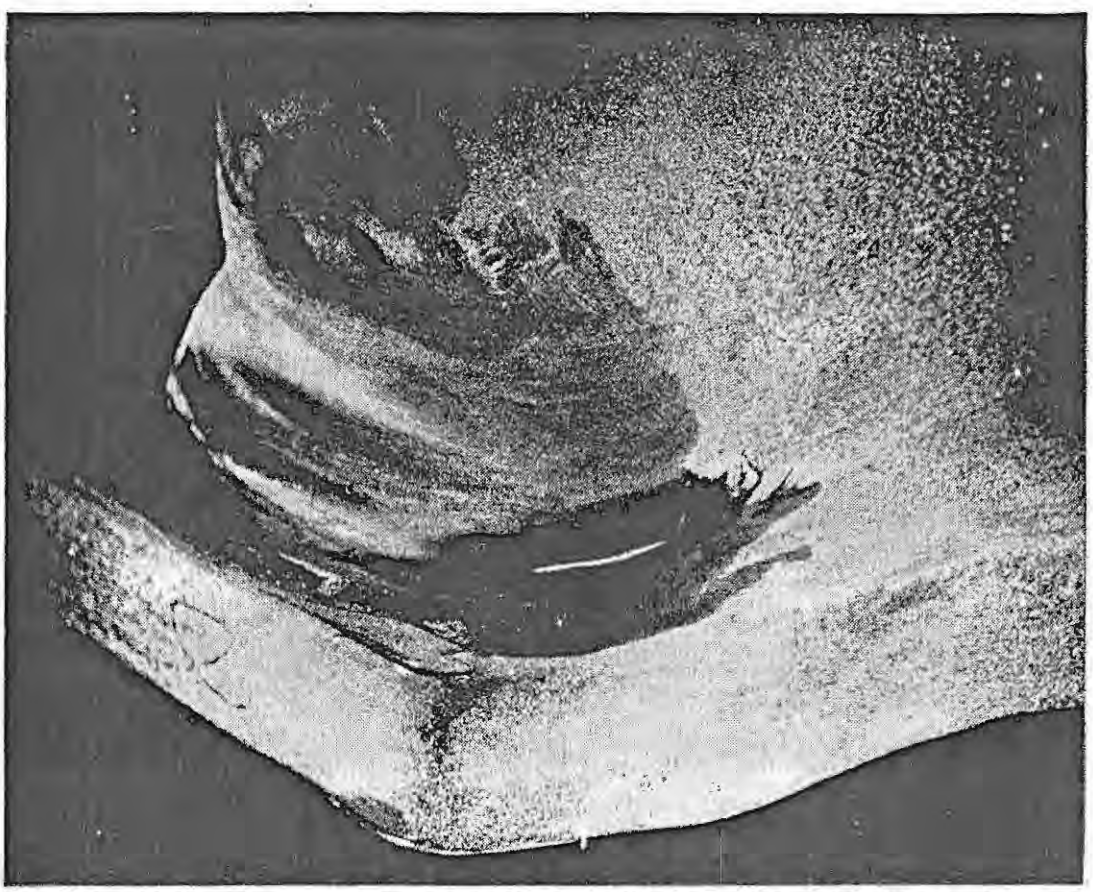

Fig. 16.11 Fluorescent Partek indication. *Courtesy of Magnaflux Corporation.*

with it. If a crack is present, a large amount of liquid will be drawn to the defect, and a large number of particles dispersed through the liquid, as indicated above, will be filtered out at the surface to reveal its location. Partek particles are colored to contrast with the work and give good visibility. One type of Partek particle is intended to reveal defects at or near the surface of work that is not worth repairing. Another type is designed to penetrate into deep cracks so that colored indications may be followed to their full depths in removing and repairing defects. Fluorescent Partek particles are available to reveal defects as glowing lines of color when viewed in black light. A fluorescent Partek indication, shown in Fig. 16.11, marks a normally invisible crack in an unfired clay body. Crack re-

moval before firing prevents scrap in finished products and leads to quicker correction of errors in primary assembly or processes.

Ultrasonic Testing: The Sonizon[1]

The Sonizon is an electronic instrument that is designed to measure the thickness of sound-conducting materials up to 4 in. thick, and to detect laminar subsurface defects which may be present in them. Measurements are made from one side of the work only; and its thickness, or the depth of a hidden flaw, is read on a linear scale across the face of a cathode-ray tube.

During the operation of a Sonizon, an oscillator in the instrument generates a high-frequency current that is varied constantly throughout its tuning range by a motor-driven variable condenser. These high-frequency impulses are fed into a quartz crystal, in a hand probe, which changes them into sound waves. The sound waves are transmitted to the material that is to be examined, through close contact between it and the crystal, then to the opposite face of the material which reflects the waves back to the crystal. When a sound wave which has been reflected back to the crystal arrives there at the same instant that the next one leaves, a change of energy is transmitted to the electrical circuits in the instrument. This change of energy is amplified to cause a peak or "pip" to appear on the oscilloscope scale to indicate the thickness of the material.

Sonizon scales are printed on transparent plastic sheets which may be mounted in a slide in front of the face of the cathode-ray tube. The speed of sound in different materials is known; therefore, Sonizon scales are calibrated to read thicknesses of various materials directly in thousandths of an inch. Each scale covers a 2 to 1 range of thicknesses for a given material; that is, the maximum dimension on a scale is twice its minimum dimension. For example, typical full-range scales could be

a. 0.014 to 0.028 in.
b. 0.025 to 0.050 in.

[1] The Sonizon is a type of electronic measuring instrument that is manufactured by Magnaflux Corporation under license from General Motors Corporation.

c. 0.045 to 0.090 in.
d. 0.080 to 0.160 in.
e. 0.150 to 0.300 in.

Any similar 2 to 1 range can be set up for the direct reading of values between 0.010 and 0.400 in. Thicknesses between 0.400 and 4.000 in. are read from harmonic peaks by applying the formula

$$T = N \times \frac{R_1 \times R_2}{R_2 - R_1}$$

where T = thickness of the material.
R_1 = lower of two harmonic peaks used.
R_2 = higher of two harmonic peaks used.
N = number of peaks between R_1 and R_2.

The use of a Sonizon to measure the thickness of large steel tubing from one side only is illustrated in Fig. 16.12. Crystal contact against the tubing surface, oiled to provide coupling between the

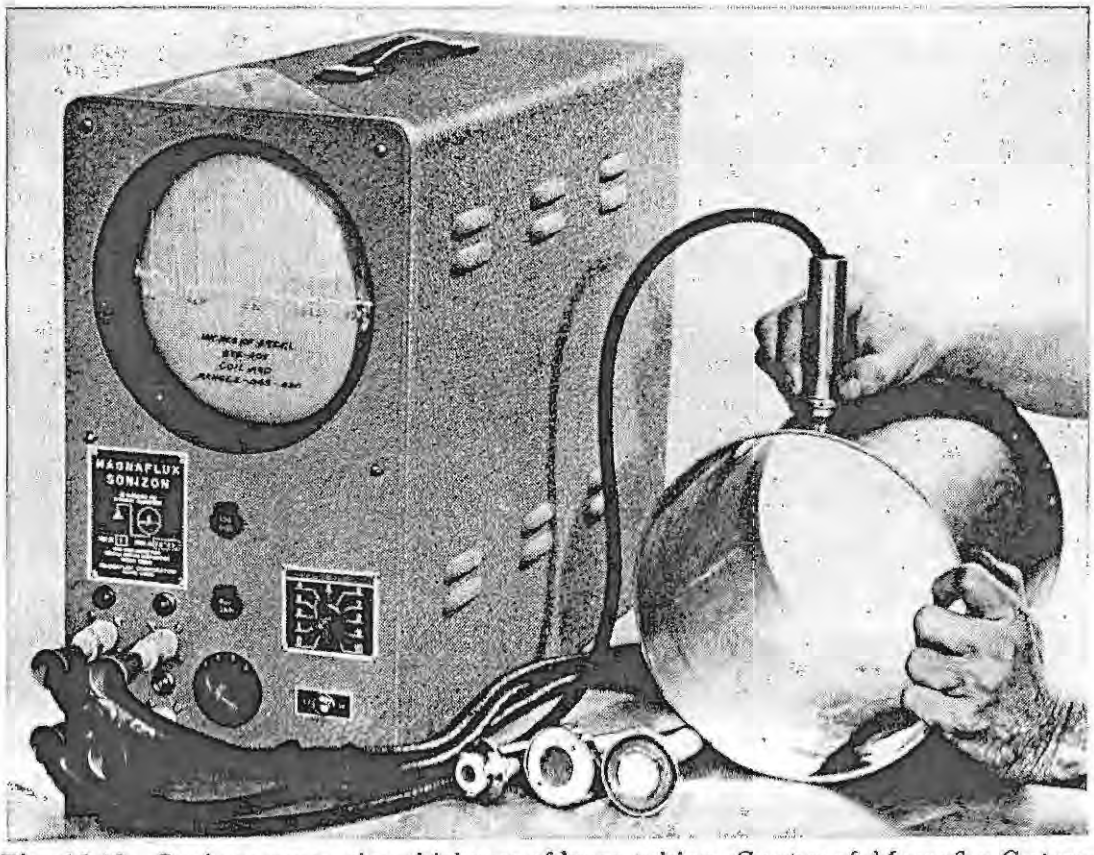

Fig. 16.12 Sonizon measuring thickness of large tubing. *Courtesy of Magnaflux Corporation.*

crystal and tube, gives a "pip" which may be read on the scaled screen at 0.040 in.

A Sonizon is being used in Fig. 16.13 to measure thickness on a formed and welded sheet-metal refrigerator case after grinding

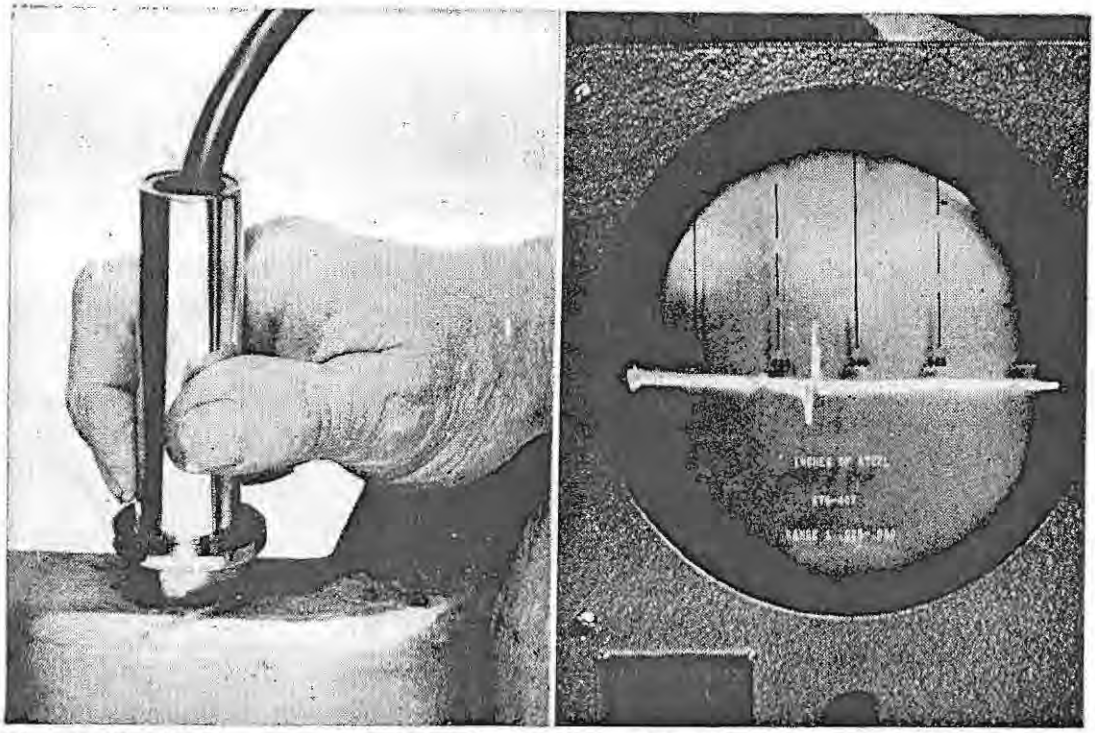

Fig. 16.13 Sonizon measuring thickness of a welded sheet-metal refrigerator case. *Courtesy of Magnaflux Corporation.*

has removed the weld and an indeterminate amount of the metal. The screen reading showing at the right gives a thickness of 0.037 in.

Radiographic Inspection

X-rays produced by cathode-ray tubes and gamma rays emitted by radioactive materials are radiations of such short wavelengths that they can penetrate matter, impervious to light, and affect photographic film and fluorescent screens behind it. The intensity of radiation that passes through an object varies with its thickness and density. That is, a thick section of an object absorbs more radiation than a thin section, and dense matter absorbs more radiation than less dense materials. This property of x-rays and gamma rays is employed to make radiographs or shadow pictures in which (*a*) thick sections of an object show as light areas, and thin parts or

voids appear as contrasting darker or black areas; and (*b*) dense materials show as dark areas, and less dense materials as lighter areas.

Radiographs are used in the inspection of industrial raw materials and products to reveal flaws in metals, the omission or improper placements of inserts in moulded plastics and die castings, the use of defective components or the omission of parts in assembled products, the inclusion of foreign bodies in packaged goods, and for many similar applications. In metal-working industries, radiographs are employed most often to inspect castings and weldments to see that they are structurally sound. They may, however, be used to examine all forms of metallic raw materials and products.

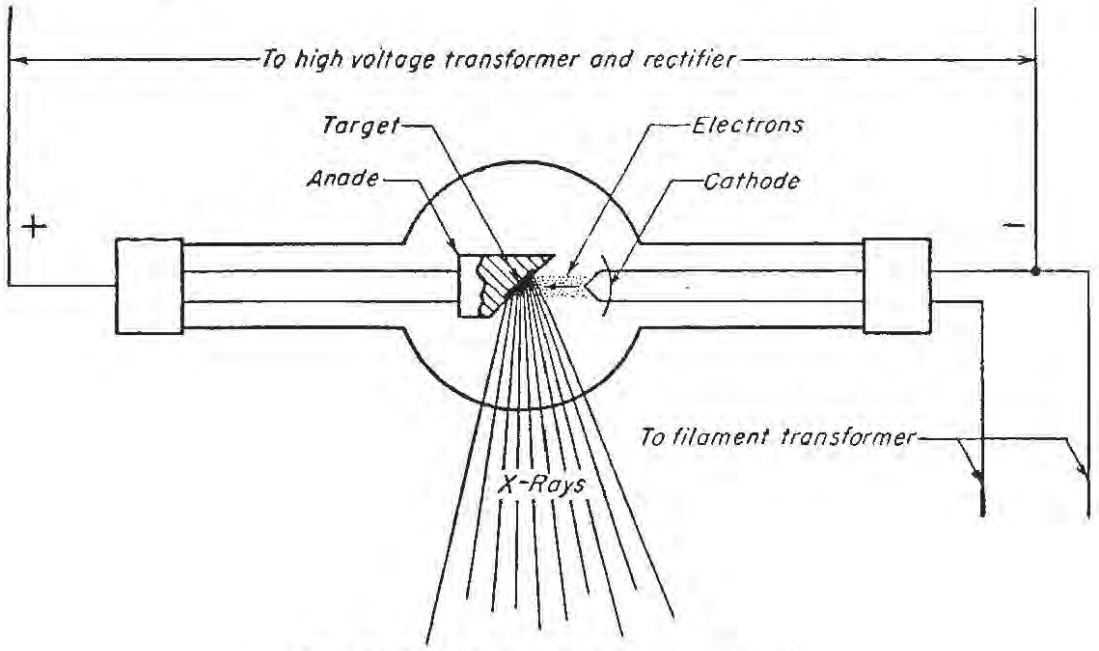

Fig. 16.14 Diagram of an x-ray tube.

X-ray Inspection

The source of radiation for industrial x-ray inspection is the Coolidge x-ray tube which is shown in diagramatic form in Fig. 16.14. The tube, usually of glass, is evacuated of air as completely as possible. In it, electrons are generated by a filament of tungsten wire that is heated to a high temperature by an electric current.

Electrons that evaporate from the hot cathode are focused on a target in the angular end of a copper anode, and they acquire an enormous speed in their passage from one to the other because of a high difference in potential maintained between the two parts. When the electrons strike the target, part of their kinetic energy is transformed into x-rays which are focused on the work to be inspected, and the remainder is transformed into heat which is carried away by a cooling system in the anode.

Typical apparatus for x-ray inspection operates on 110-volt or 220-volt alternating current and consists of an autotransformer, to control the voltage that is applied to a high-voltage x-ray transformer; an x-ray transformer and rectifier tubes, to transform the alternating current to high-voltage direct current, to maintain the cathode-anode potential in the x-ray tube; filament transformers, to supply current of the proper voltages for the filaments of the x-ray and rectifier tubes; switches, meters, automatic timer, and manual controls, to regulate the current in the different electrical circuits; an oil circulating system, to cool the anode; the x-ray tube; and an adjustable unit, for moving the tube over a wide area and positioning it to radiograph the work.

Industrial x-ray units are made in different sizes and types which adapt them to various applications. The 250-kv single-column Tubestand, shown in Fig. 16.15, is an industrial x-ray unit that is designed for use in locations where the amount of floor space that can be devoted to x-ray inspection equipment is limited. The unit consists of a fabricated steel base with provisions for leveling and fastening it to the floor, a chromium-plated steel column that encloses a counterweight, a tubearm, and a tubehead. The tubearm assembly may be rotated about the column and adjusted vertically and horizontally; and the tubehead may be rotated 180 deg in either direction about the center line of the tubearm and about 140 deg about its own long axis so that the x-ray tube may be positioned anywhere within the range of the unit for inspecting work. The unit shown in this illustration will radiograph 4½ in. of steel, and proportionally thicker sections of lighter density materials.

A 150-kv wall-mounted unit, especially designed for light work, is shown in Fig. 16.16. The tubehead, which is mounted on a flexible, self-balancing arm, is excellent for use in foundries, welding shops, pipe shops, or other plants requiring light x-ray inspection.

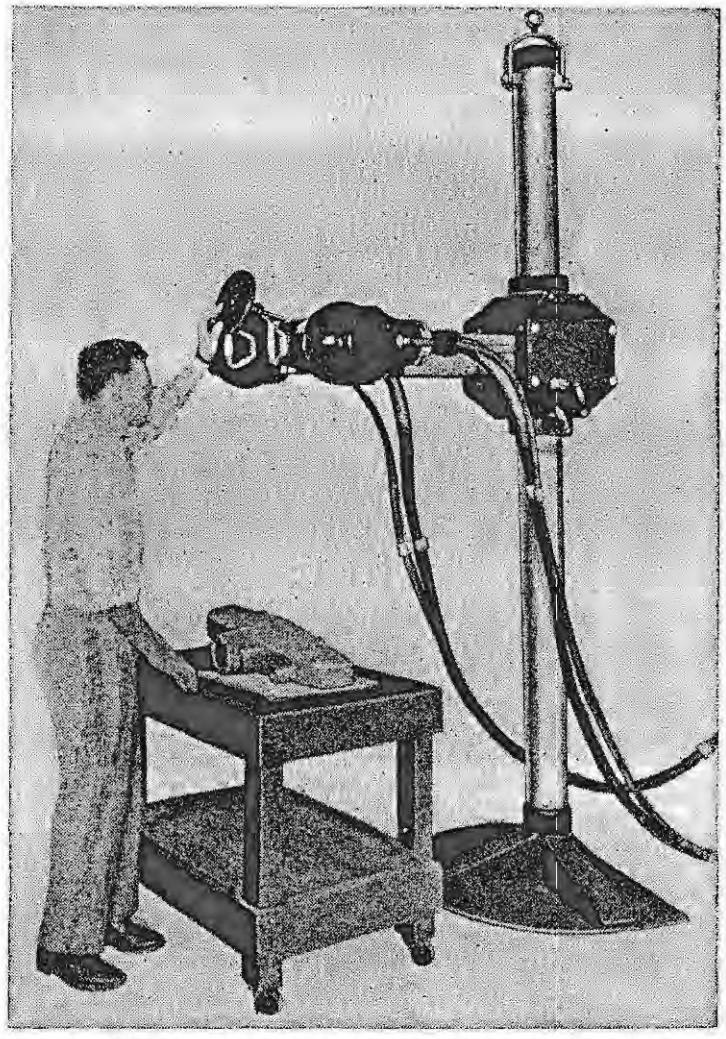

Fig. 16.15 250-kv single-column tubestand. Industrial x-ray unit in action. *Courtesy of Westinghouse Electric Corporation.*

Using intensifying screens, this unit will examine 1½ in. of steel, 1 in. of brass, or 7½ in. of aluminum. Without screens, it will examine 1 in. of steel with higher definition. The screens referred to, which are coated with fluorescent material, are placed in contact with the x-ray film. They absorb energy from the x-rays and emit the energy again as blue-violet light which intensifies the effect of the x-rays on the sensitized film.

Other models of x-ray equipment, not illustrated in this article, consist of truck-mounted units for portability, crane-mounted units for extra-wide range in the area that may be covered, and self-contained units for installation in production lines for mass inspection of manufactured parts.

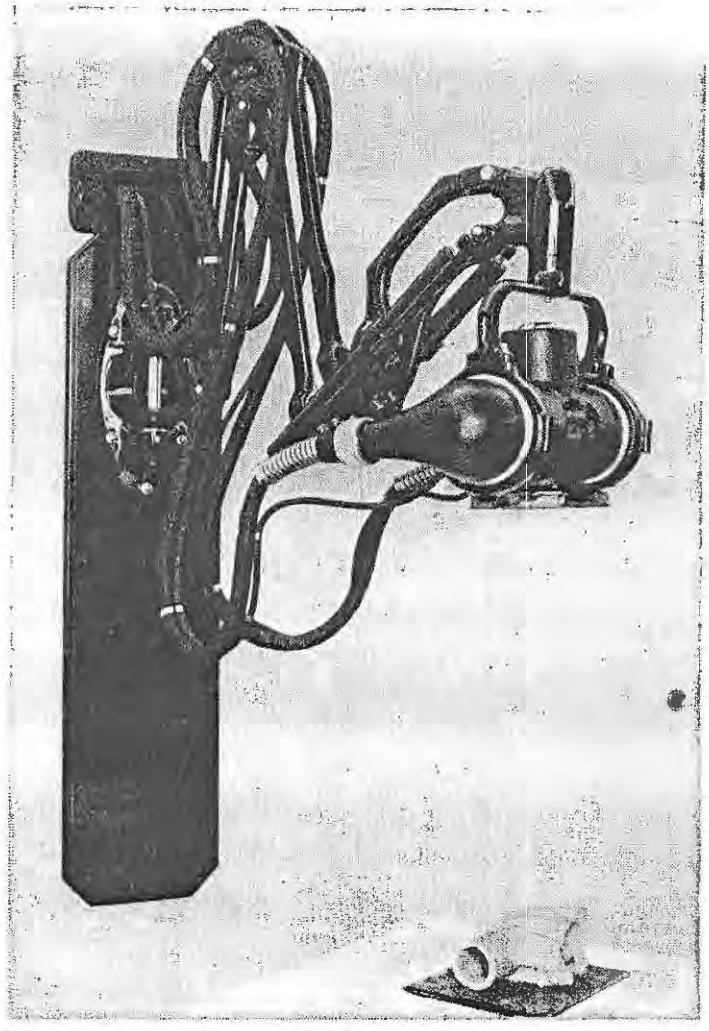

Fig. 16.16 150-kv wall-mounted industrial x-ray unit. *Courtesy of Westinghouse Electric Corporation.*

A radiograph of the sand casting seen in Fig. 16.16 is shown in Fig. 16.17. No discernable flaws are visible in this picture.

A weld radiograph is shown in Fig. 16.18. The black dots in the picture indicate gas inclusions, white dots represent metal spatter, and a small transverse black line near the middle of the picture reveals a very fine stress crack.

After exposure, x-ray film is processed in the same manner as

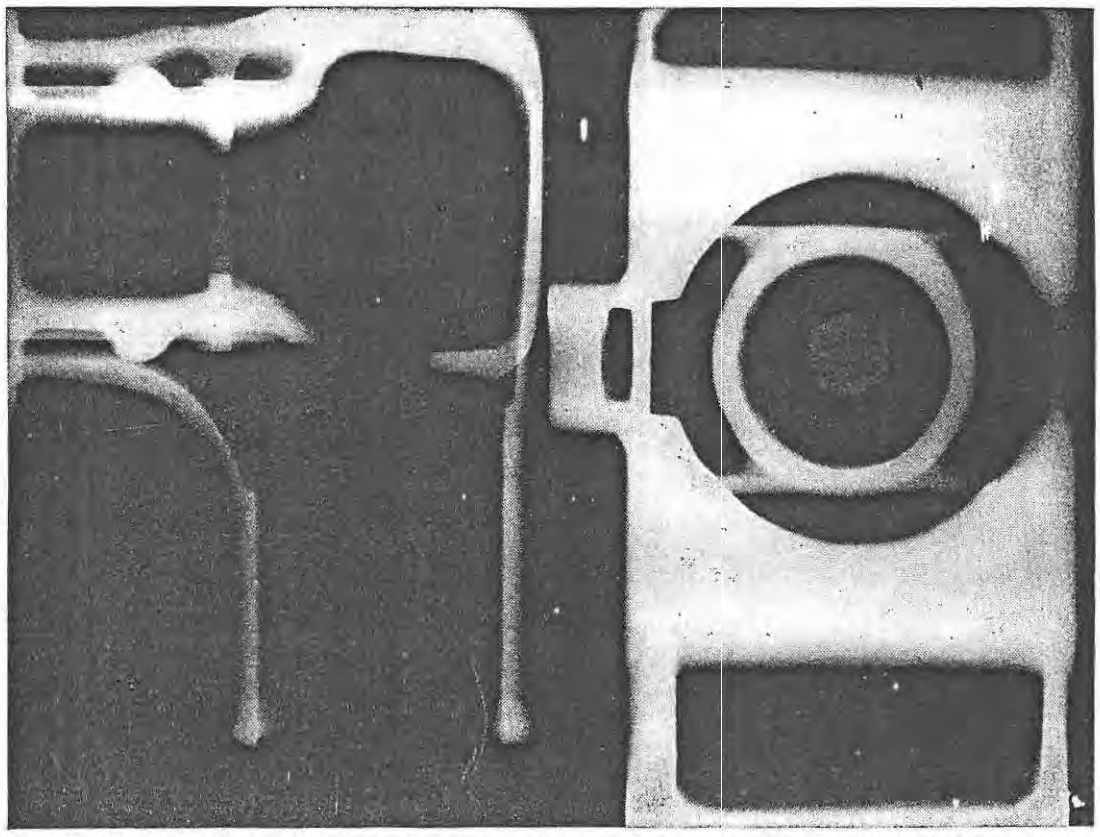

Fig. 16.17 Radiograph of sand casting shown in Fig. 16.14. *Courtesy of Westinghouse Electric Corporation.*

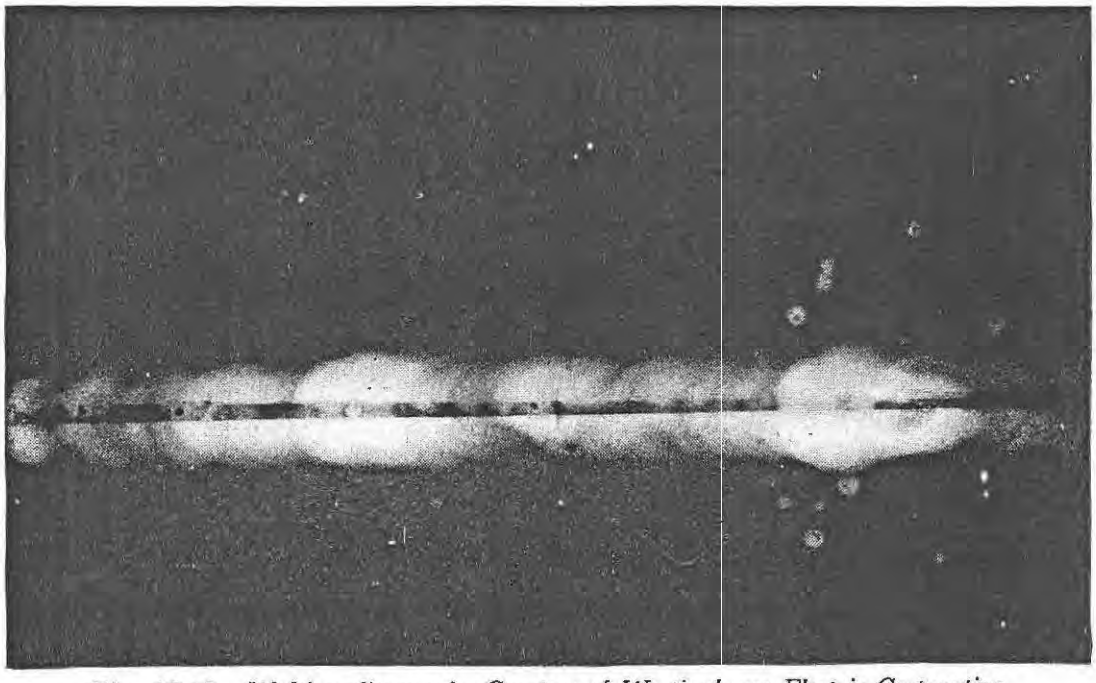

Fig. 16.18 Weld radiograph. *Courtesy of Westinghouse Electric Corporation.*

other photographic film. Usually, the developed film is held in an illuminator for direct examination; however, prints may be made as in Figs. 16.17 and 16.18.

Fluoroscopic Inspection

Low-density materials that are penetrated readily by x-rays may be inspected with fluoroscopic equipment. In this method, the x-ray tube is placed beneath the work, and the shadow image is formed on a fluorescent screen which is located between the work and the inspector. The fluoroscope, for use in industrial inspection, is usually enclosed in a lead-lined cabinet and is provided with a means of conveying specimens to the point where they are examined by the operator who views the work through lead glass or a system of mirrors. This precaution, together with the lead-lined cabinet, serves to protect the inspector against the harmful effects of x-radiations. This method is used extensively to inspect packaged foods to detect foreign matter in them, and in the plastic and die-casting industries.

Radium and Radioactive-isotope Radiography

Radium is customarily used in the form of radium sulfate that is densely packed in a cylindrical silver container which is brazed airtight. The silver cylinder is then inserted in a larger egg-shaped container made of aluminum or steel. The aluminum type is handled by means of strings attached to eyelets on the capsule, and the steel container may be handled by means of a magnetic handling arrangement.

In general, radium is used to inspect objects where it is difficult to position an x-ray tube to obtain a successful radiograph; as, for example, in the interior of hollow cylindrical objects which have a small diameter. In most cases, radium radiography is not considered as satisfactory as x-ray radiography. It does, however, have its uses, particularly where the x-ray unit cannot be taken to the work, or the work cannot be taken to the x-ray tube. Radium radiography is a simpler operation than x-ray radiography in that

there are no controls to operate. Another factor which is an advantage is that there is less scattering of rays resulting from the object being inspected so that little blocking of the object is required. The quality of the gamma-ray beam is high and within a relatively narrow range of wavelengths. This means that the beam is able to penetrate quite heavy material with clarity of detail.

Compared with x-ray radiography, there are many disadvantages. Major ones are:

1. The intensity of a source up to 500 mg of radium is low compared to x-ray radiography. This indicates that exposure times are in periods of hours instead of minutes.

2. To obtain maximum intensity of the beam, sources up to 500 mg of radium are used. The smallest radium capsule, which is the 25 mg, is a sphere approximately 3 mm (0.118 in.) in diameter, and the largest capsule of 500 mg rating is 10 mm (0.394 in.) in diameter by 7 mm (0.276 in.) high. This means that the effective radiation source size is considerably larger than that used in ordinary industrial x-ray equipment. Therefore, geometrical distortion is greater than that in x-ray radiography. Also, to increase the effective intensity reaching the film, the radium source is ordinarily employed at distances which are considered too close for x-ray radiography, and the geometrical distortion is increased by the small source-film distance.

3. Since the general radiation given off is within a relatively narrow band of wavelengths, the resulting negative is rather flat; that is, the contrast of a radiograph taken with radium is low, and sensitivity suffers.

Radioactive isotopes are employed in the same manner as radium. However, the intensity of the radiation can be many times as high as that from an equivalent weight of radium. The cost in comparison is low. Various wavelength bands are produced depending upon the isotope; and the isotopes are used for specific applications where radium could be used, but the result would not be favorable or the exposure time would be entirely too long. The radioactive isotope most commonly used is cobalt 60. Radioactive isotopes

have one major disadvantage in comparison with radium because their half-life values are comparatively short.

In radiographic inspection, the operator and others in the vicinity of the operation must be protected against direct radiation from the source and against scatter rays reflected from the work and its surroundings. Protection is afforded by lining the room or cabinet where the operation is performed with sheet lead or by shielding the operation as completely as possible with lead sheets. Heavy brick or concrete walls may be employed instead of lead lining to afford protection in some installations.

No detailed instructions have been given for operating types of equipment described in this chapter. When information of that nature is required, operator's manuals should be consulted.

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QUESTIONS

1. Describe, briefly, the Magnaflux process of inspection.

2. How does the Magnaglo process of inspection differ from the Magnaflux process?

3. Name a process that reveals surface defects by the use of electrified particles.

4. Name two processes that employ filtered particles to locate defects in work.

5. Describe the ultrasonic method used to measure the thickness of sound-conducting materials or to detect subsurface defects in them.

6. Two kinds of rays, having very short wavelengths, may be used to photograph matter that is impervious to light so that hidden flaws and other defects may be revealed. Name them, and state how the rays are produced.

17

STATISTICAL QUALITY CONTROL

"Statistical quality control," or more simply "quality control" is a term that is employed to designate the use of statistical methods in conjunction with the inspection of manufactured products to accomplish two principal objectives:

1. To prevent the production of defective articles by inspecting work and establishing control over manufacturing processes during production, instead of waiting to inspect it after operations have been completed when it is too late to take corrective action.

2. To reduce the number, and therefore the cost, of inspection operations, and at the same time, to ensure the delivery of acceptable quality to the purchaser of a product by adopting a sampling inspection plan that is based on statistical methods.

Although the foregoing objectives have been stated separately, a combination of both is very often involved in applications of statistical quality control. Their separation, however, is useful in developing an understanding of the concepts that underlie the methods which are employed.

In addition to accomplishing the primary objectives that have been stated, applications of quality control may result in investigations which will lead to improved inspection methods, improved manufacturing methods, and improved product specifications.

The quality of a manufactured product may be defined as its

conformance to specifications. It is generally recognized that no two units of a product are ever exactly alike. Inspection will always show that there is variation from an ideal value, provided the measuring instrument is sensitive enough to reveal it. In manufacturing practice, therefore, the specification for any product characteristic represents its ideal value with a plus or minus, or both, permissible variation from that ideal which is called "tolerance." The maximum and minimum values between which the product may vary are called "specification limits."

Variations in a product are due to slight differences in successive units of raw material, wear on tools, changed settings on machines, fluctuations in power, changes in temperature, and numerous other causes that may be classified in two groups as:

1. *Chance causes:* Chance causes are those that are inherent in the raw material, maufacturing process, and method of measuring the product. They occur at random, and result in variations which are so small that their elimination cannot be justified economically.

2. *Assignable causes:* Assignable causes are those that result from trouble in the manufacturing process. Their presence is indicated by large variations in the quality of the product, and they should be identified and eliminated if possible.

As long as chance factors only are the cause of variation, any given characteristic of a product will remain within the limits specified for it, and the manufacturing process is said to be in a state of control. When an assignable cause of variation enters the process, however, the product tends to and will eventually exceed the established limits, and the process is out of control.

One use of quality control is its application to determine when an assignable cause of variation enters a manufacturing process in time to take corrective action which will prevent the production of defective articles. The tool that is used to accomplish this is the quality-control chart.

A quality-control chart (Fig. 17.1) is a graphical device on which measurements of a quality characteristic are recorded so that their trend may be observed. The chart consists of:

1. A vertical scale of values at the left-hand side.

2. A horizontal central line that is drawn from a point which represents the average value on the vertical scale.

3. Two control limits that are drawn parallel to, and at equal distances above and below the central line. These are called the upper and lower control limits, respectively. There is an exception to this symmetrical arrangement of control limits on some charts.

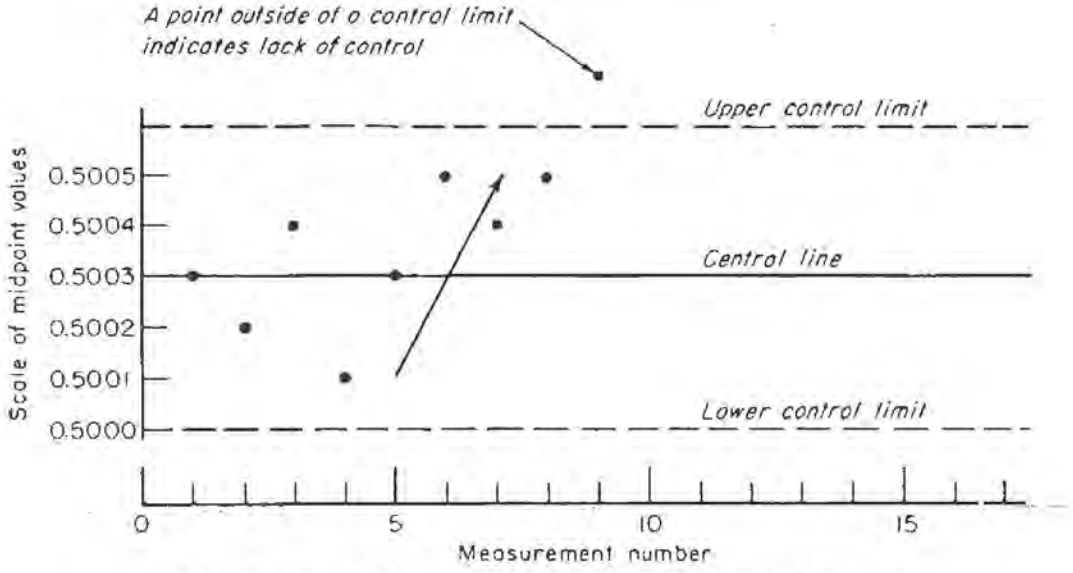


Fig. 17.1 Elements of a quality-control chart.

4. A fourth horizontal line is drawn at either the top or bottom of the chart. This is essentially and in some cases actually a time scale. It is uniformly divided and is used to indicate the order in which measurements are made and recorded.

Points are plotted on the control chart to record data about the quality of the characteristic that is being inspected.

Two kinds of inspection may be employed to gather data about the quality characteristics of a manufactured product. In one method, called "inspection by variables," the product is measured with a graduated tool or instrument to determine how much it varies from the ideal value which is specified for it. In the other method, called "inspection by attributes," the product is measured with a "go not go" type of inspection tool to determine if it lies

within the limits of variability established for it. The data which are gathered take one of three forms:

1. Inspection by variables gives a record of the actual measurements of the product.

2. Inspection by attributes gives a record of the total number of items examined and the number found to be defective. This record may be expressed as the fraction defective, per cent defective, or number defective in a sample or lot of designated size. Variability is shown by a difference in the number of defectives from sample-to-sample or lot-to-lot.

3. Inspection by attributes may also give a record of the number of defects in a unit or given number of units of the product.

Each point that is plotted on a control chart may represent the measurement of a single unit of the product, or it may represent the average of several units taken as a sample.

The control limits on a quality-control chart may consist of specification limits that are established by an engineering department to define a quality which is wanted in a product. It should be recalled, however, that a quality-control chart is used to analyze the quality which is produced by a manufacturing process, and by that means, to determine when an assignable cause of variation enters the process so that it may be investigated and eliminated. To do this, the lines on the control chart must be located by using information that is gathered from the process itself.

The most important values for analyzing variation in a set of measurements for quality control are the average and the standard deviation or the range. The average serves to locate the central tendency of the measurements, and the standard deviation or the range serves to show their dispersion about the average. One method of obtaining these values consists of arranging the measurements in a frequency distribution as a preliminary to further analysis.

A *frequency distribution* is an arrangement of numerical data according to size and frequency. It takes the form shown in Fig. 17.2, which represents recorded outside-diameter measurements of 64

Diameter	*Tally*	f	$f \times M.P.$
0.5006	𝍸	1	$1 \times 6^* = 6$
0.5005	𝍸 𝍸	6	$6 \times 5 = 30$
0.5004	𝍸 𝍸 𝍸	15	$15 \times 4 = 60$
0.5003	𝍸 𝍸 𝍸 𝍸	20	$20 \times 3 = 60$
0.5002	𝍸 𝍸 𝍸	15	$15 \times 2 = 30$
0.5001	𝍸 𝍸	6	$6 \times 1 = 6$
0.5000	𝍸	1	$1 \times 0 = 0$
		$64 = N$	$192 = \Sigma(f \times M.P.)$

$$\bar{X} = {}^{192}\!/_{64} = 3 = 0.5003$$

One formula for computing the arithmetic mean of a frequency distribution is

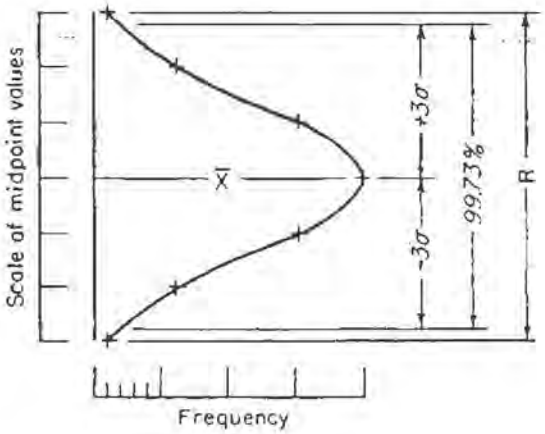
$$\bar{X} = \frac{\Sigma(f \times M.P.)}{N}$$

where $\bar{X}$ = arithmetic mean.
Σ = Greek upper-case letter sigma meaning "sum of."
f = frequency of occurrence.
$M.P.$ = mid-point value. Mid-point values, in this case, are the diameters.
N = number of items.

Fig. 17.2 A frequency distribution and its arithmetic mean.

steel pins arranged according to size. This figure also serves to illustrate one method of computing the average or arithmetic mean of a frequency distribution.

A normal frequency distribution is exactly symmetrical about its arithmetic mean; that is, values which are at equal distances from the arithmetic mean have equal frequencies. This condition is illustrated by the normal probability curve in Fig. 17.3, which was constructed by drawing a smoothed curve through the maximum value of each group, or class, in the frequency distribution shown in Fig. 17.2. The normal curve has been analyzed by mathematicians, and the percentage of items located at various dis-



$\bar{X}$ = arithmetic mean

σ = Greek lower-case letter sigma meaning "standard deviation"

R = Range, the difference between the largest and smallest values in a set of numbers

Fig. 17.3 Normal curve of probability.

* To simplify computation, 0.5000 is subtracted from the diameters, and the remainder is treated as a whole number. The process is reversed at the end of the computation.

tances from the arithmetic mean, measured in terms of standard deviations, has been determined and tabulated. For example, it is known that 99.73 per cent, or practically all, of the items in a normal frequency distribution lie within ± 3 standard deviations either side of the arithmetic mean. Although normal distributions seldom occur in practice, many are so near that they may be treated as normal without appreciable error. For these reasons, therefore, the control limits on a quality-control chart are usually located at ± 3 standard deviations when this measure is used to judge dispersion in quality-control work.

Diameter	*Tally*	f	x	x^2	$f(x^2)$
0.5006	|	1	+3*	9	9
0.5005	𝍸 |	6	+2	4	24
0.5004	𝍸 𝍸 𝍸	15	+1	1	15
0.5003	𝍸 𝍸 𝍸 𝍸	20	0	0	0
0.5002	𝍸 𝍸 𝍸	15	−1	1	15
0.5001	𝍸 |	6	−2	4	24
0.5000	|	1	−3	9	9
		$\overline{64} = N$			$\overline{96} = \Sigma f(x^2)$

$$\sigma = \sqrt{\tfrac{96}{64}} = 1.224+ \qquad 3\sigma = 3.672+ = 0.0003672+$$

One formula for computing the standard deviation of a frequency distribution is

$$\sigma = \sqrt{\frac{\Sigma f(x^2)}{N}}$$

where σ = Greek lower-case letter sigma meaning "standard deviation."
Σ = Greek upper-case letter sigma meaning "sum of."
f = frequency of occurrence.
x = deviation of each group from the arithmetic mean (0.5003 from Fig. 17.2).
N = number of items.

Fig. 17.4 A frequency distribution and its standard deviation.

The standard deviation is the root-mean-square (rms) deviation of observed values about the arithmetic mean. One method of calculating this measure is illustrated in Fig. 17.4. Notice that the same data which have been used previously were employed in constructing this figure.

The range is the difference between the largest and smallest values in a series of measurements. It may be used as the measure of dispersion to locate control limits in preference to the standard

* To simplify computation, 0.5000 is subtracted from the diameters, and the remainder is treated as a whole number. The decimal is restored at the end of the computation.

deviation because it requires subtraction only instead of computing squares and square roots.

A control chart for average alone may be used when experience indicates that lack of control is associated with conditions that affect the average only. Similarly, a control chart for the standard deviation or the range alone may be used when lack of control is associated with causes that affect the extreme values only. The use of two charts, one for average and the other for standard deviation or range may be useful in other situations. A control chart for fraction defective, per cent defective, or number defective is necessary when the inspection record consists of the total number of units examined and the number of them found to be defective. And a control chart for the number of defects is required when a count of the defects in a designated amount or quantity of the product comprises the inspection record.

Quality-control charts may be used in conjunction with either one hundred per cent or sampling inspection.

One hundred per cent inspection and sorting good from bad units are necessary to assure complete conformity of a product to its specifications. Even then, some defective units will be overlooked through failure of an inspector or his instruments. Sampling inspection is necessary when the testing process destroys the product, and when the cost of one hundred per cent inspection cannot be absorbed in the selling price of the product.

In sampling inspection, one or more specimens are drawn from a lot of the product and examined. The sample is considered to be representative of the lot; and the lot is accepted, inspected further, or rejected on the showing of the sample. A representative sample is a random sample drawn from a homogeneous lot or subgroup. That is, the specimens are drawn from the lot in such a manner that one unit is as likely to be selected as any other; and the lot is from a single source, such as a single machine in a battery of similar machines, or the product from a specific heat from a furnace, etc.

It is obvious that sampling inspection cannot guarantee delivery of one hundred per cent perfect product to the customer and that it

may be used only when the customer is willing to accept some defective units in order to secure a lower cost. It is apparent, also, that a small sampling will decrease the cost of inspection but will increase the "consumer's risk" because some bad lots of the product will pass inspection. Conversely, a large sampling will increase the cost but decrease the "consumer's risk." A "producer's risk" also exists because some good lots of product may be rejected by inspectors during the sampling inspection. Every sampling plan, therefore, involves a compromise between cost and risk.

Numerous sampling plans are possible. Those that are based on statistical methods are designed by applying the laws of chance to such factors as lot size, sample size, average quality produced by the manufacturing process, consumer's risk, and other elements in order to determine the "acceptance number" for the sample; that is, the number of defectives allowable in the sample. Standard tables that give this information for various single and multiple sampling plans which are in common use have been published so that a knowledge of elementary arithmetic is sufficient to permit inspectors to carry on this work.

In one variation of single sampling, the sample is inspected. If the acceptance number is not exceeded, the lot is accepted; but if it is exceeded, the remainder of the lot is inspected, defective units are replaced with good ones, and the lot is accepted.

In double sampling, a first sample is inspected. If the acceptance number is not exceeded, the lot is accepted; but if it is exceeded, a second sample is drawn and inspected. If the acceptance number for the first and second samples combined is not exceeded the lot is accepted; but if it is exceeded, the lot is rejected.

In a sequential sampling plan, there are both acceptance and rejection numbers for a sequence of samples. In its operation, a first sample is drawn and inspected. If the acceptance number is reached without finding a defective unit, the lot is accepted. If a defective is found, the inspection is continued; and if the number of defectives reaches the rejection number, the lot is rejected. But if the number of defectives lies between the acceptance and rejection numbers, a

second sample is drawn and the process is repeated. This process of acceptance, rejection, or continuation is repeated until a final decision is reached or until the entire lot has been inspected.

This brief description of statistical quality control will serve to introduce the concepts that are the foundation of the subject. The mathematics of probability were avoided deliberately. If a more extensive knowledge of the subject is desired, it may be obtained by referring to books in the bibliography that follows.

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QUESTIONS

1. What are the two primary objectives of statistical quality control?
2. List three additional benefits that may result from applications of statistical quality control.
3. Describe a quality-control chart and explain how it is used.

4. How is inspection by variables performed?

5. How is inspection by attributes performed?

6. What are the three most important values for analyzing variations in a set of measurements for the purpose of quality control?

7. What is the significance of ± 3 standard deviations in establishing the control limits on a quality control chart?

8. Will 100 per cent inspection assure complete conformance of a manufactured product with its specifications? Discuss.

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APPENDIX

Suggestions for Conducting Inspection Practice

Inspection problems, to give practice in the use of measuring tools, may consist of rough, semifinished, or finished machine parts obtained from the regular production of a shop, or they may consist of parts specially made for the purpose. Enough parts of a kind should be provided so that practice in repetitive measurement is possible, and some should be acceptable, while others are defective. To assist in checking work sheets quickly, each part of a kind should be marked with a serial number.

1. Parts, a working drawing (Fig. A.1), and necessary measuring tools may be given to a student who is required to perform an acceptance or sorting type of inspection with them.

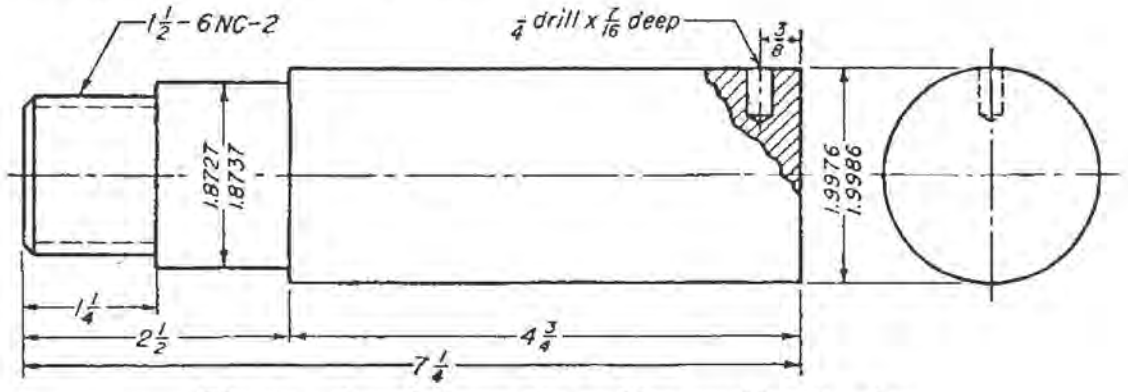

Fig. A.1 Sample inspection problem working drawing.

2. Parts, a drawing with letters instead of dimensions (Fig. A.2), a work sheet (Fig. A.3), and measuring tools are given to a student who is required to record his measurements of the parts on the work sheet. This may be compared with a master sheet to check his accuracy quickly.

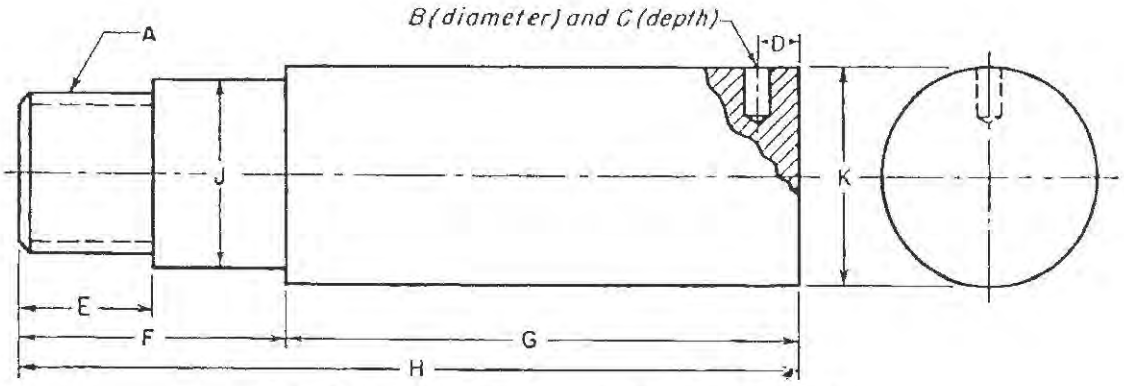

Fig. A.2 Sample inspection problem drawing.

WORK SHEET

Problem number _____

Measurement	*Part serial number*									
	1	2	3	4	5	6	7	8	9	10
A										
B										
C										
D										
E										
F										
G										
H										
I										
J										
K										
L										
M										
N										
O										
P										
Q										
R										
S										
T										
U										
V										
W										
X										
Y										
Z										

Fig. A.3 Sample inspection problem work sheet.

Parts of any one kind, of course, will permit practice in the use of several tools. For example, dimension K, Fig. A.2, may be measured with an outside caliper and steel rule, and outside micrometer caliper, vernier caliper, comparator, etc.

It is not necessary that all students shall work on the same problem at one time.

Table 1 DECIMAL EQUIVALENTS OF EIGHTHS, SIXTEENTHS, THIRTY-SECONDS, AND SIXTY-FOURTHS OF AN INCH

$\frac{1}{64} = 0.015625$	$\frac{33}{64} = 0.515625$
$\frac{1}{32} = 0.03125$	$\frac{17}{32} = 0.53125$
$\frac{3}{64} = 0.046875$	$\frac{35}{64} = 0.546875$
$\frac{1}{16} = 0.0625$	$\frac{9}{16} = 0.5625$
$\frac{5}{64} = 0.078125$	$\frac{37}{64} = 0.578125$
$\frac{3}{32} = 0.09375$	$\frac{19}{32} = 0.59375$
$\frac{7}{64} = 0.109375$	$\frac{39}{64} = 0.609375$
$\frac{1}{8} = 0.125$	$\frac{5}{8} = 0.625$
$\frac{9}{64} = 0.140625$	$\frac{41}{64} = 0.640625$
$\frac{5}{32} = 0.15625$	$\frac{21}{32} = 0.65625$
$\frac{11}{64} = 0.171875$	$\frac{43}{64} = 0.671875$
$\frac{3}{16} = 0.1875$	$\frac{11}{16} = 0.6875$
$\frac{13}{64} = 0.203125$	$\frac{45}{64} = 0.703125$
$\frac{7}{32} = 0.21875$	$\frac{23}{32} = 0.71875$
$\frac{15}{64} = 0.234375$	$\frac{47}{64} = 0.734375$
$\frac{1}{4} = 0.250$	$\frac{3}{4} = 0.750$
$\frac{17}{64} = 0.265625$	$\frac{49}{64} = 0.765625$
$\frac{9}{32} = 0.28125$	$\frac{25}{32} = 0.78125$
$\frac{19}{64} = 0.296875$	$\frac{51}{64} = 0.796875$
$\frac{5}{16} = 0.3125$	$\frac{13}{16} = 0.8125$
$\frac{21}{64} = 0.328125$	$\frac{53}{64} = 0.828125$
$\frac{11}{32} = 0.34375$	$\frac{27}{32} = 0.84375$
$\frac{23}{64} = 0.359375$	$\frac{55}{64} = 0.859375$
$\frac{3}{8} = 0.375$	$\frac{7}{8} = 0.875$
$\frac{25}{64} = 0.390625$	$\frac{57}{64} = 0.890625$
$\frac{13}{32} = 0.40625$	$\frac{29}{32} = 0.90625$
$\frac{27}{64} = 0.421875$	$\frac{59}{64} = 0.921875$
$\frac{7}{16} = 0.4375$	$\frac{15}{16} = 0.9375$
$\frac{29}{64} = 0.453125$	$\frac{61}{64} = 0.953125$
$\frac{15}{32} = 0.46875$	$\frac{31}{32} = 0.96875$
$\frac{31}{64} = 0.484375$	$\frac{63}{64} = 0.984375$
$\frac{1}{2} = 0.500$	$1 = 1.000$

Table 2 ENGLISH-MEASURE GRADUATIONS

No. 1 Graduation	
1st edge	10, 20, 50, 100
2d edge	12, 24, 48
3d edge	16, 32, 64
4th edge	14, 28
No. 2 Graduation	
1st edge	10, 20, 50, 100
2d edge	12, 24, 48
3d edge	16, 32, 64
4th edge	8
No. 4 Graduation	
1st edge	64
2d edge	32
3d edge	16
4th edge	8
No. 7 Graduation	
1st edge	64
2d edge	32
3d edge	16
4th edge	100
No. 10 Graduation	
1st edge	32
2d edge	64
No. 11 Graduation	
1st edge	64
2d edge	100
No. 12 Graduation	
1st edge	50
2d edge	100
No. 16 Graduation	
1st edge	32
2d edge	64
3d edge	50
4th edge	100

Table 3 SIZE IN INCHES OF GAGE BLOCKS IN AN 81-BLOCK SET

0.0001 in. series—9 blocks

0.1001	0.1002	0.1003	0.1004	0.1005	0.1006	0.1007	0.1008	0.1009

0.001 in. series—49 blocks

0.101	0.102	0.103	0.104	0.105	0.106	0.107	0.108	0.109	0.110
0.111	0.112	0.113	0.114	0.115	0.116	0.117	0.118	0.119	0.120
0.121	0.122	0.123	0.124	0.125	0.126	0.127	0.128	0.129	0.130
0.131	0.132	0.133	0.134	0.135	0.136	0.137	0.138	0.139	0.140
0.141	0.142	0.143	0.144	0.145	0.146	0.147	0.148	0.149	

0.050-in. series—19 blocks

0.050	0.100	0.150	0.200	0.250	0.300	0.350	0.400	0.450	0.500
0.550	0.600	0.650	0.700	0.750	0.800	0.850	0.900	0.950	

1.000-in. series—4 blocks

1.000	2.000	3.000	4.000

Table 4 CONVERSION OF INTERFERENCE BANDS TO INCHES

Bands	*Inches*	*Bands*	*Inches*	*Bands*	*Inches*
0.1	0.0000012	1.0	0.0000116	11.0	0.0001272
0.2	0.0000023	2.0	0.0000231	12.0	0.0001388
0.3	0.0000035	3.0	0.0000347	13.0	0.0001504
0.4	0.0000046	4.0	0.0000463	14.0	0.0001619
0.5	0.0000058	5.0	0.0000578	15.0	0.0001735
0.6	0.0000069	6.0	0.0000694	16.0	0.0001851
0.7	0.0000081	7.0	0.0000810	17.0	0.0001966
0.8	0.0000093	8.0	0.0000925	18.0	0.0002082
0.9	0.0000104	9.0	0.0001041	19.0	0.0002198
		10.0	0.0001157	20.0	0.0002313

Table 5 GAGEMAKERS' TOLERANCES

Nominal Size						
Above	*To and Including*	*Class XX**	*Class X*	*Class Y*	*Class Z*	*Class ZZ†*
0.029	0.825	0.00002	0.00004	0.00007	0.00010	0.00020
0.825	1.510	0.00003	0.00006	0.00009	0.00012	0.00024
1.510	2.510	0.00004	0.00008	0.00012	0.00016	0.00032
2.510	4.510	0.00005	0.00010	0.00015	0.00020	0.00040
4.510	6.510	0.000065	0.00013	0.00019	0.00025	0.00050
6.510	9.010	0.00008	0.00016	0.00024	0.00032	0.00064
9.010	12.010	0.00010	0.00020	0.00030	0.00040	0.00080

* Internal or plug gages only.
† External or ring gages only.

Table 6 NATURAL TRIGONOMETRIC FUNCTIONS

Angle	sin	cos	tan	cot	sec	csc	Angle
0	.0000	1.0000	.0000	.....	1.0000	.....	90°
1	.0175	.9998	.0175	57.2900	1.0002	57.2987	89
2	.0349	.9994	.0349	28.6363	1.0006	28.6537	88
3	.0523	.9986	.0524	19.0811	1.0014	19.1073	87
4	.0698	.9976	.0699	14.3007	1.0024	14.3356	86
5	.0872	.9962	.0875	11.4301	1.0038	11.4737	85
6	.1045	.9945	.1051	9.5144	1.0055	9.5668	84
7	.1219	.9925	.1228	8.1443	1.0075	8.2055	83
8	.1392	.9903	.1405	7.1154	1.0098	7.1853	82
9	.1564	.9877	.1584	6.3138	1.0125	6.3925	81
10	.1736	.9848	.1763	5.6713	1.0154	5.7588	80
11	.1908	.9816	.1944	5.1446	1.0187	5.2408	79
12	.2079	.9781	.2126	4.7046	1.0223	4.8097	78
13	.2250	.9744	.2309	4.3315	1.0263	4.4454	77
14	.2419	.9703	.2493	4.0108	1.0306	4.1336	76
15	.2588	.9659	.2679	3.7321	1.0353	3.8637	75
16	.2756	.9613	.2867	3.4874	1.0403	3.6280	74
17	.2924	.9563	.3057	3.2709	1.0457	3.4203	73
18	.3090	.9511	.3249	3.0777	1.0515	3.2361	72
19	.3256	.9455	.3443	2.9042	1.0576	3.0716	71
20	.3420	.9397	.3640	2.7475	1.0642	2.9238	70
21	.3584	.9336	.3839	2.6051	1.0711	2.7904	69
22	.3746	.9272	.4040	2.4751	1.0785	2.6695	68
23	.3907	.9205	.4245	2.3559	1.0864	2.5593	67
24	.4067	.9135	.4452	2.2460	1.0946	2.4586	66
25	.4226	.9063	.4663	2.1445	1.1034	2.3662	65
26	.4384	.8988	.4877	2.0503	1.1126	2.2812	64
27	.4540	.8910	.5095	1.9626	1.1223	2.2027	63
28	.4695	.8829	.5317	1.8807	1.1326	2.1301	62
29	.4848	.8746	.5543	1.8040	1.1434	2.0627	61
30	.5000	.8660	.5774	1.7321	1.1547	2.0000	60
31	.5150	.8572	.6009	1.6643	1.1666	1.9416	59
32	.5299	.8480	.6249	1.6003	1.1792	1.8871	58
33	.5446	.8387	.6494	1.5399	1.1924	1.8361	57
34	.5592	.8290	.6745	1.4826	1.2062	1.7883	56
35	.5736	.8192	.7002	1.4281	1.2208	1.7434	55
36	.5878	.8090	.7265	1.3764	1.2361	1.7013	54
37	.6018	.7986	.7536	1.3270	1.2521	1.6616	53
38	.6157	.7880	.7813	1.2799	1.2690	1.6243	52
39	.6293	.7771	.8098	1.2349	1.2868	1.5890	51
40	.6428	.7660	.8391	1.1918	1.3054	1.5557	50
41	.6561	.7547	.8693	1.1504	1.3250	1.5243	49
42	.6691	.7431	.9004	1.1106	1.3456	1.4945	48
43	.6820	.7314	.9325	1.0724	1.3673	1.4663	47
44	.6947	.7193	.9657	1.0355	1.3902	1.4396	46
45	.7071	.7071	1.0000	1.0000	1.4142	1.4142	45
Angle	cos	sin	cot	tan	csc	sec	Angle

Table 7 CONSTANTS FOR USE IN MEASURING DOVETAILS WITH WIRES OR RODS

Constant	*Angle a*			
	45°	50°	55°	60°
C	3.4142	3.1445	2.9210	2.7320
K	2.0000	1.6782	1.4004	1.1547

Table 8 FORMULAS FOR COMPUTING DIMENSIONS OF TAPERS

$$T = 12\left(\frac{D-d}{L}\right)$$

$$t = \frac{D-d}{L}$$

$$D = d + (tL)$$

$$d = D - (tL)$$

$$L = \frac{D-d}{t}$$

Taper in $L = t \times L$

Table 9 AMERICAN NATIONAL STANDARD SCREW THREADS

Sizes and Pitches of Coarse-thread Series

No. 1-64	No. ¼ -20	No. 1 -8	No. 2¾-4
No. 2-56	No. 5/16-18	No. 1⅛-7	No. 3 -4
No. 3-48	No. ⅜ -16	No. 1¼-7	No. 3¼-4
No. 4-40	No. 7/16-14	No. 1⅜-6	No. 3½-4
No. 5-40	No. ½ -13	No. 1½-6	No. 4 -4
No. 6-32	No. 9/16-12	No. 1¾-5	
No. 8-32	No. ⅝ -11	No. 2 -4½	
No. 10-24	No. ¾ -10	No. 2¼-4½	
No. 12-24	No. ⅞ - 9	No. 2½-4	

Table 10 AMERICAN NATIONAL STANDARD SCREW THREADS

Sizes and Pitches of Fine-thread Series

No. 0-80	No. 5-44	No. ¼ -28	No. 9/16-18	No. 1⅛-12
No. 1-72	No. 6-40	No. 5/16-24	No. ⅝ -18	No. 1¼-12
No. 2-64	No. 8-36	No. ⅜ -24	No. ¾ -16	No. 1⅜-12
No. 3-56	No. 10-32	No. 7/16-20	No. ⅞ -14	No. 1½-12
No. 4-48	No. 12-28	No. ½ -20	No. 1 -14	

Table 11 SCALES OF HARDNESS

	Mohs	*Knoop*
1.	Talc	
2.	Gypsum	32
3.	Calcite	135
4.	Fluorite	163
5.	Apatite	360–430
6.	Orthoclase	560
7.	Quartz	710
8.	Topaz	1,250
9.	Sapphire	1,525–2,000
10.	Diamond	5,800–6,200

Table 12 BRINELL HARDNESS NUMBERS*

Diameter of Steel Ball, 10 mm

Diameter of ball impression, mm	*Hardness number for a load*		*Diameter of ball impression, mm*	*Hardness number for a load*		*Diameter of ball impression, mm*	*Hardness number for a load*		*Diameter of ball impression, mm*	*Hardness number for a load*		*Diameter of ball impression, mm*	*Hardness number for a load*	
	500 *kg*	3,000 *kg*		500 *kg*	3,000 *kg*		500 *kg*	3,000 *kg*		500 *kg*	3,000 *kg*		500 *kg*	3,000 *kg*
2.00	158	945	3.00	69.1	415	4.00	38.1	229	5.00	23.8	143	6.00	15.9	95.5
2.05	150	899	3.05	66.8	401	4.05	37.1	223	5.05	23.3	140	6.05	15.6	93.7
2.10	143	856	3.10	64.6	388	4.10	36.2	217	5.10	22.8	137	6.10	15.3	92.0
2.15	136	817	3.15	62.5	375	4.15	35.3	212	5.15	22.3	134	6.15	15.1	90.3
2.20	130	780	3.20	60.5	363	4.20	34.4	207	5.20	21.8	131	6.20	14.8	88.7
2.25	124	745	3.25	58.6	352	4.25	33.6	201	5.25	21.4	128	6.25	14.5	87.1
2.30	119	712	3.30	56.8	341	4.30	32.8	197	5.30	20.9	126	6.30	14.2	85.5
2.35	114	682	3.35	55.1	331	4.35	32.0	192	5.35	20.5	123	6.35	14.0	84.0
2.40	109	653	3.40	53.4	321	4.40	31.2	187	5.40	20.1	121	6.40	13.7	82.5
2.45	104	627	3.45	51.8	311	4.45	30.5	183	5.45	19.7	118	6.45	13.5	81.0
2.50	100	601	3.50	50.3	302	4.50	29.8	179	5.50	19.3	116	6.50	13.3	79.6
2.55	96.3	578	3.55	48.9	293	4.55	29.1	174	5.55	18.9	114	6.55	13.0	78.2
2.60	92.6	555	3.60	47.5	285	4.60	28.4	170	5.60	18.6	111	6.60	12.8	76.8
2.65	89.0	534	3.65	46.1	277	4.65	27.8	167	5.65	18.2	109	6.65	12.6	75.4
2.70	85.7	514	3.70	44.9	269	4.70	27.1	163	5.70	17.8	107	6.70	12.4	74.1
2.75	82.6	495	3.75	43.6	262	4.75	26.5	159	5.75	17.5	105	6.75	12.1	72.8
2.80	79.6	477	3.80	42.4	255	4.80	25.9	156	5.80	17.2	103	6.80	11.9	71.6
2.85	76.8	461	3.85	41.3	248	4.85	25.4	152	5.85	16.8	101	6.85	11.7	70.4
2.90	74.1	444	3.90	40.2	241	4.90	24.8	149	5.90	16.5	99.2	6.90	11.5	69.2
2.95	71.5	429	3.95	39.1	235	4.95	24.3	146	5.95	16.2	97.3	6.95	11.3	68.0

* Courtesy of Tinius Olsen Testing Machine Co.

Table 13 SCALES FOR ROCKWELL NORMAL TESTER

The symbol for use as a prefix to the value read from the dial depends upon the load, type of penetrator and scale from which dial readings are taken, and these symbols are shown below.

Scale symbol	*Penetrator*	*Load, kg*	*Dial figures*
B	1/16-in. ball	100	Red
C	Brale	150	Black
A	Brale	60	Black
D	Brale	100	Black
E	1/8-in. ball	100	Red
F	1/16-in. ball	60	Red
G	1/16-in. ball	150	Red
H	1/8-in. ball	60	Red
K	1/8-in. ball	150	Red
L	1/4-in. ball	60	Red
M	1/4-in. ball	100	Red
P	1/4-in. ball	150	Red
R	1/2-in. ball	60	Red
S	1/2-in. ball	100	Red
V	1/2-in. ball	150	Red

Table 14 SCALES FOR ROCKWELL SUPERFICIAL TESTER

The symbols for use as a prefix to the value read from the dial depends upon the load, type of penetrator, and scale from which dial readings are taken; these symbols are shown below.

Scale symbol	*Penetrator*	*Load, kg*
15N	Brale	15
30N	Brale	30
45N	Brale	45
15T	1/16-in. ball	15
30T	1/16-in. ball	30
45T	1/16-in. ball	45
15W	1/8-in. ball	15
30W	1/8-in. ball	30
45W	1/8-in. ball	45
15X	1/4-in. ball	15
30X	1/4-in. ball	30
45X	1/4-in. ball	45
15Y	1/2-in. ball	15
30Y	1/2-in. ball	30
45Y	1/2-in. ball	45

NOTE TO TABLES 15 AND 16*

All so-called "conversion" tables of hardness scales, including those here published, are and must be based on the assumption that the metal tested is homogeneous to a depth several times as great as the depth of the indentation, because different loads and different shapes of penetrators would, in metal not homogeneous, penetrate or at least meet the resistance of metal of varying hardness, depending upon the depth of the indentation; hence, no definite hardness value would actually exist and no recorded hardness value would be valid to an extent that could be confirmed by another person unless shape of penetrator and actual load applied are both specified.

These fundamentally essential specifications as to both loads and penetrators are and always have been fully covered in the recording of readings obtained on Rockwell hardness testers by the use of alphabetical symbols.

Conversion tables dealing with hardness can be only approximate and never mathematically exact, for it must be understood that a penetration hardness test proceeds until the specimen tested supports the applied load. Yet it is a severely cold-worked metal that actually supports the penetrator, and different metals, different alloys, and different analyses of the same type of alloy, have different cold-working properties. Nevertheless, while a conversion table cannot be mathematically exact, it is of considerable value to be able to compare different hardness scales in a general way.

* Courtesy of Wilson Mechanical Instrument Co., Inc.

Table 15 APPROXIMATE RELATIONSHIPS BETWEEN HARDNESS VALUES DETERMINED ON ROCKWELL AND ROCKWELL SUPERFICIAL HARDNESS TESTERS AND VALUES DETERMINED ON OTHER TESTERS*

For Hardened Steel and Hard Alloys

C	*A*	*D*	15†-*N*	30†-*N*	45†-*N*	*Diamond pyramid*	*Brinell*	*G*	*Tensile strength*
Rockwell hardness tester C scale Brale penetrator—150-kg load	*Rockwell hardness tester A scale Brale penetrator—60-kg load*	*Rockwell hardness tester D scale Brale penetrator—100-kg load*	*Rockwell Superficial 15-N scale N Brale penetrator—15-kg load*	*Rockwell Superficial 30-N scale N Brale penetrator—30-kg load*	*Rockwell Superficial 45-N scale N Brale penetrator—45-kg load*	*4-sided 136° diamond pyramid 10-kg load—measurement of 2 diagonals by microscope. Hardness numbers computed by formula.*	*Brinell, standard-type, 3,000-kg load Hultgren 10-mm ball penetrator*	*Rockwell hardness tester G-scale 1/16-in. ball penetrator—150-kg load*	*1,000 psi*
80	92.0	86.5	96.5	92.0	87.0	1865			
79	91.5	85.5	....	91.5	86.5	1787			
78	91.0	84.5	96.0	91.0	85.5	1710			
77	90.5	84.0	....	90.5	84.5	1633			
76	90.0	83.0	95.5	90.0	83.5	1556			
75	89.5	82.5	....	89.0	82.5	1478			
74	89.0	81.5	95.0	88.5	81.5	1400			
73	88.5	81.0	....	88.0	80.5	1323			
72	88.0	80.0	94.5	87.0	79.5	1245			
71	87.0	79.5	....	86.5	78.5	1160			
70	86.5	78.5	94.0	86.0	77.5	1076			
69	86.0	78.0	93.5	85.0	76.5	1004			
68	85.5	77.0	....	84.5	75.5	942			
67	85.0	76.0	93.0	83.5	74.5	894			
66	84.5	75.5	92.5	83.0	73.0	854			
65	84.0	74.5	92.0	82.0	72.0	820			
64	83.5	74.0	....	81.0	71.0	789			
63	83.0	73.0	91.5	80.0	70.0	763			
62	82.5	72.5	91.0	79.0	69.0	739			
61	81.5	71.5	90.5	78.5	67.5	716			
60	81.0	71.0	90.0	77.5	66.5	695	614	....	314
59	80.5	70.0	89.5	76.5	65.5	675	600	....	306
58	80.0	69.0	....	75.5	64.0	655	587	....	299
57	79.5	68.5	89.0	75.0	63.0	636	573	....	291
56	79.0	67.5	88.5	74.0	62.0	617	560	....	284
55	78.5	67.0	88.0	73.0	61.0	598	547	....	277
54	78.0	66.0	87.5	72.0	59.5	580	534	....	270
53	77.5	65.5	87.0	71.0	58.5	562	522	....	263
52	77.0	64.5	86.5	70.5	57.5	545	509	....	256
51	76.5	64.0	86.0	69.5	56.0	528	496	....	250

Note: General conversion values on material harder than about C-70 on the Rockwell hardness tester will probably be long in dispute because as yet there are few materials hard enough to be brought into that study and because some of those few do not flow nicely under the testing load but have a tendency to crumble and others do not approach homogeneity.

Inexact and only for steel

* Courtesy of Wilson Mechanical Instrument Co., Inc.

† The 15-T, 30-T, 45-T, 15-N, 30-N and 45-N values are in scales of the Rockwell Superficial hardness tester, a specialized form of Rockwell tester, having lighter loads and more sensitive depth reading system, used where for one or another reason the indentation must be exceptionally shallow.

Table 15 APPROXIMATE RELATIONSHIPS BETWEEN HARDNESS VALUES DETERMINED ON ROCKWELL AND ROCKWELL SUPERFICIAL HARDNESS TESTERS AND VALUES DETERMINED ON OTHER TESTERS.* *(Continued)*

C	*A*	*D*	15†-*N*	30†-*N*	45†-*N*	*Diamond pyramid*	*Brinell*	*G*	*Tensile strength*
Rockwell hardness tester C scale Brale penetrator—150-kg load	*Rockwell hardness tester A scale Brale penetrator—60-kg load*	*Rockwell hardness tester D scale Brale penetrator—100-kg load*	*Rockwell Superficial 15-N scale N Brale penetrator—15-kg load*	*Rockwell Superficial 30-N scale N Brale penetrator—30-kg load*	*Rockwell Superficial 45-N scale N Brale penetrator—45-kg load*	*4-sided 136° diamond pyramid 10-kg load—measurement of 2 diagonals by microscope. Hardness numbers computed by formula.*	*Brinell, standard-type, 3,000-kg load Hultgren 10 mm ball penetrator*	*Rockwell hardness tester G scale ½ 6-in. ball penetrator—150-kg load*	*1,000 psi*
50	76.0	63.0	85.5	68.5	55.0	513	484	....	243
49	75.5	62.0	85.0	67.5	54.0	498	472	....	236
48	74.5	61.5	84.5	66.5	52.5	485	460	....	230
47	74.0	60.5	84.0	66.0	51.5	471	448	....	223
46	73.5	60.0	83.5	65.0	50.0	458	437	....	217
45	73.0	59.0	83.0	64.0	49.0	446	426	....	211
44	72.5	58.5	82.5	63.0	48.0	435	415	....	205
43	72.0	57.5	82.0	62.0	46.5	424	404	....	199
42	71.5	57.0	81.5	61.5	45.5	413	393	....	194
41	71.0	56.0	81.0	60.5	44.5	403	382	....	188
40	70.5	55.5	80.5	59.5	43.0	393	372	....	182
39	70.0	54.5	80.0	58.5	42.0	383	362	....	177
38	69.5	54.0	79.5	57.5	41.0	373	352	....	171
37	69.0	53.0	79.0	56.5	39.5	363	342	....	166
36	68.5	52.5	78.5	56.0	38.5	353	332	....	162
35	68.0	51.5	78.0	55.0	37.0	343	322	....	157
34	67.5	50.5	77.0	54.0	36.0	334	313	....	153
33	67.0	50.0	76.5	53.0	35.0	325	305	....	148
32	66.5	49.0	76.0	52.0	33.5	317	297	....	144
31	66.0	48.5	75.5	51.5	32.5	309	290	....	140
30	65.5	47.5	75.0	50.5	31.5	301	283	92.0	136
29	65.0	47.0	74.5	49.5	30.0	293	276	91.0	132
28	64.5	46.0	74.0	48.5	29.0	285	270	90.0	129
27	64.0	45.5	73.5	47.5	28.0	278	265	89.0	126
26	63.5	44.5	72.5	47.0	26.5	271	260	88.0	123
25	63.0	44.0	72.0	46.0	25.5	264	255	87.0	120
24	62.5	43.0	71.5	45.0	24.0	257	250	86.0	117
23	62.0	42.5	71.0	44.0	23.0	251	245	84.5	115
22	61.5	41.5	70.5	43.0	22.0	246	240	83.5	112
21	61.0	41.0	70.0	42.5	20.5	241	235	82.5	110
20	60.5	40.0	69.5	41.5	19.5	236	230	81.0	108

Table 16 APPROXIMATE RELATIONSHIPS BETWEEN HARDNESS VALUES DETERMINED ON ROCKWELL AND ROCKWELL SUPERFICIAL HARDNESS TESTERS AND VALUES DETERMINED ON OTHER TESTERS*

For Unhardened Steel, Steel of Soft Temper, Grey and Malleable Cast Iron and Most Nonferrous Metal

B	*F*	*G*	15†-*T*	30†-*T*	45†-*T*	*E*	*H*	*K*	*A*	*Brinell*	*Brinell*	*Tensile Strength*
Rockwell hardness tester B scale 1/16-*in. ball penetrator—* 100-*kg load*	*Rockwell hardness tester F scale* 1/16-*in. ball penetrator—* 60-*kg load*	*Rockwell hardness tester G scale* 1/16-*in. ball penetrator—* 150-*kg load*	*Rockwell Superficial 15-T scale* 1/16-*in. ball penetrator—* 15-*kg load*	*Rockwell Superficial 30-T scale* 1/16-*in. ball penetrator—* 30-*kg load*	*Rockwell Superficial 45-T scale* 1/16-*in. ball penetrator—* 45-*kg load*	*Rockwell hardness tester E scale* 1/8-*in. ball penetrator—* 100-*kg load*	*Rockwell hardness tester H scale* 1/8-*in. ball penetrator—* 60-*kg load*	*Rockwell hardness tester K scale* 1/8-*in. ball penetrator—* 150-*kg load*	*Rockwell hardness tester A scale Brale penetrator—* 60-*kg load*	*Brinell, standard-type, 500-kg load 10-mm ball penetrator*	*Brinell, standard-type, 3,000-kg load 10-mm ball penetrator*	1,000 *psi*
100	....	82.5	93.0	82.0	72.0	.....	....	.....	61.5	201	240	116
99	....	81.0	92.5	81.5	71.0	.....	....	.....	61.0	195	234	112
98	....	79.0	....	81.0	70.0	.....	....	.....	60.0	189	228	109
97	....	77.5	92.0	80.5	69.0	.....	....	.....	59.5	184	222	106
96	....	76.0	....	80.0	68.0	.....	....	.....	59.0	179	216	103
95	....	74.0	91.5	79.0	67.0	.....	....	.....	58.0	175	210	101
94	....	72.5	....	78.5	66.0	.....	....	.....	57.5	171	205	98
93	....	71.0	91.0	78.0	65.5	.....	....	.....	57.0	167	200	96
92	....	69.0	90.5	77.5	64.5	.....	....	100	56.5	163	195	93
91	....	67.5	....	77.0	63.5	.....	....	99.5	56.0	160	190	91
90	....	66.0	90.0	76.0	62.5	.....	....	98.5	55.5	157	185	89
89	....	64.0	89.5	75.5	61.5	.....	....	98.0	55.0	154	180	87
88	....	62.5	....	75.0	60.5	.....	....	97.0	54.0	151	176	85
87	....	61.0	89.0	74.5	59.5	.....	....	96.5	53.5	148	172	83
86	....	59.0	88.5	74.0	58.5	.....	....	95.5	53.0	145	169	81
85	....	57.5	....	73.5	58.0	.....	....	94.5	52.5	142	165	80
84	....	56.0	88.0	73.0	57.0	.....	....	94.0	52.0	140	162	78
83	....	54.0	87.5	72.0	56.0	.....	....	93.0	51.0	137	159	77
82	....	52.5	....	71.5	55.0	.....	....	92.0	50.5	135	156	75
81	....	51.0	87.0	71.0	54.0	.....	....	91.0	50.0	133	153	74
80	....	49.0	86.5	70.0	53.0	.....	....	90.5	49.5	130	150	72
79	....	47.5	....	69.5	52.0	.....	....	89.5	49.0	128	147	
78	....	46.0	86.0	69.0	51.0	.....	....	88.5	48.5	126	144	
77	....	44.0	85.5	68.0	50.0	.....	....	88.0	48.0	124	141	
76	....	42.5	....	67.5	49.0	.....	....	87.0	47.0	122	139	
75	99.5	41.0	85.0	67.0	48.5	.....	....	86.0	46.5	120	137	
74	99.0	39.0	....	66.0	47.5	.....	....	85.0	46.0	118	135	
73	98.5	37.5	84.5	65.5	46.5	.....	....	84.5	45.5	116	132	
72	98.0	36.0	84.0	65.0	45.5	.....	....	83.5	45.0	114	130	
71	97.5	34.5	....	64.0	44.5	100	....	82.5	44.5	112	127	
70	97.0	32.5	83.5	63.5	43.5	99.5	....	81.5	44.0	110	125	
69	96.0	31.0	83.0	62.5	42.5	99.0	....	81.0	43.5	109	123	
68	95.5	29.5	....	62.0	41.5	98.0	....	80.0	43.0	107	121	
67	95.0	28.0	82.5	61.5	40.5	97.5	....	79.0	42.5	106	119	
66	94.5	26.5	82.0	60.5	39.5	97.0	....	78.0	42.0	104	117	
65	94.0	25.0	....	60.0	38.5	96.0	....	77.5	....	102	116	
64	93.5	23.5	81.5	59.5	37.5	95.5	....	76.5	41.5	101	114	
63	93.0	22.0	81.0	58.5	36.5	95.0	....	75.5	41.0	99	112	
62	92.0	20.5	....	58.0	35.5	94.5	....	74.5	40.5	98	110	
61	91.5	19.0	80.5	57.0	34.5	93.5	....	74.0	40.0	96	108	
60	91.0	17.5	....	56.5	33.5	93.0	....	73.0	39.5	95	107	
59	90.5	16.0	80.0	56.0	32.0	92.5	....	72.0	39.0	94	106	
58	90.0	14.5	79.5	55.0	31.0	92.0	....	71.0	38.5	92	104	
57	89.5	13.0	....	54.5	30.0	91.0	....	70.5	38.0	91	103	
56	89.0	11.5	79.0	54.0	29.0	90.5	....	69.5	....	90	101	
55	88.0	10.0	78.5	53.0	28.0	90.0	....	68.5	37.5	89	100	
54	87.5	8.5	....	52.5	27.0	89.5	....	68.0	37.0	87		
53	87.0	7.0	78.0	51.5	26.0	89.0	....	67.0	36.5	86		
52	86.5	5.5	77.5	51.0	25.0	88.0	....	66.0	36.0	85		
51	86.0	4.0	....	50.5	24.0	87.5	....	65.0	35.5	84		
50	85.5	2.5	77.0	49.5	23.0	87.0	....	64.5	35.0	83		

Even for steel, tensile strength relation to hardness is inexact, unless determined for specific material.

* Courtesy of Wilson Mechanical Instrument Co., Inc.

† The 15-T, 30-T, 45-T, 15-N, 30-N and 45-N values are in scales of the Rockwell Superficial hardness tester, a specialized form of Rockwell tester, having lighter loads and more sensitive depth reading system, used where for one or another reason the indentation must be exceptionally shallow.

Table 16 APPROXIMATE RELATIONSHIPS BETWEEN HARDNESS VALUES DETERMINED ON ROCKWELL AND ROCKWELL SUPERFICIAL HARDNESS TESTERS AND VALUES DETERMINED ON OTHER TESTERS.* (*Continued*)

B Rockwell hardness tester *B* scale 1/16-in. ball penetrator—100-kg load	*F* Rockwell hardness tester *F* scale 1/16-in. ball penetrator—60-kg load	*G* Rockwell hardness tester *G* scale 1/16-in. ball penetrator—150-kg load	15-*T* Rockwell Superficial 15-*T* scale 1/16-in. ball penetrator—15-kg load	30-*T* Rockwell Superficial 30-*T* scale 1/16-in. ball penetrator—30-kg load	45-*T* Rockwell Superficial 45-*T* scale 1/16-in. ball penetrator—45-kg load	*E* Rockwell hardness tester *E* scale 1/8-in. ball penetrator—100-kg load	*H* Rockwell hardness tester *H* scale 1/8-in. ball penetrator—60-kg load	*K* Rockwell hardness tester *K* scale 1/8-in. ball penetrator—150-kg load	*A* Rockwell hardness tester *A* scale Brale penetrator—60-kg load	Brinell Brinell, standard-type, 500-kg load 10-mm ball penetrator
50	85.5	2.5	77.0	49.5	23.0	87.0	....	64.5	35.0	83
49	85.0	1.0	76.5	49.0	22.0	86.5	....	63.5	....	82
48	84.5	...	....	48.5	20.5	85.5	....	62.5	34.5	81
47	84.0	...	76.0	47.5	19.5	85.0	....	61.5	34.0	80
46	83.9	...	75.5	47.0	18.5	84.5	....	61.0	33.5	
45	82.5	...	....	46.0	17.5	84.0	....	60.0	33.0	79
44	82.0	...	75.0	45.5	16.5	83.5	....	59.0	32.5	78
43	81.5	...	74.5	45.0	15.5	82.5	....	58.0	32.0	77
42	81.0	...	....	44.0	14.5	82.0	....	57.5	31.5	76
41	80.5	...	74.0	43.5	13.5	81.5	....	56.5	31.0	75
40	79.5	...	73.5	43.0	12.5	81.0	....	55.5		
39	79.0	...	....	42.0	11.0	80.0	....	54.5	30.5	74
38	78.5	...	73.0	41.5	10.0	79.5	....	54.0	30.0	73
37	78.0	...	72.5	40.5	9.0	79.0	....	53.0	29.5	72
36	77.5	...	....	40.0	8.0	78.5	100	52.0	29.0	
35	77.0	...	72.0	39.5	7.0	78.0	99.5	51.5	28.5	71
34	76.5	...	71.5	38.5	6.0	77.0	99.0	50.5	28.0	70
33	75.5	...	....	38.0	5.0	76.5	....	49.5	....	69
32	75.0	...	71.0	37.5	4.0	76.0	98.5	48.5	27.5	
31	74.5	...	....	36.5	3.0	75.5	98.0	48.0	27.0	68
30	74.0	...	70.5	36.0	2.0	75.0	....	47.0	26.5	67
29	73.5	...	70.0	35.5	1.0	74.0	97.5	46.0	26.0	
28	73.0	...	....	34.5	....	73.5	97.0	45.0	25.5	66
27	72.5	...	69.5	34.0	....	73.0	96.5	44.5	25.0	
26	72.0	...	69.0	33.0	....	72.5	....	43.5	24.5	65
25	71.0	...	....	32.5	....	72.0	96.0	42.5	....	64
24	70.5	...	68.5	32.0	....	71.0	95.5	41.5	24.0	
23	70.0	...	68.0	31.0	....	70.5	....	41.0	23.5	63
22	69.5	...	....	30.5	....	70.0	95.0	40.0	23.0	
21	69.0	...	67.5	29.5	....	69.5	94.5	39.0	22.5	62
20	68.5	...	....	29.0	....	68.5	....	38.0	22.0	
19	68.0	...	67.0	28.5	....	68.0	94.0	37.5	21.5	61
18	67.0	...	66.5	27.5	....	67.5	93.5	36.5		
17	66.5	...	....	27.0	....	67.0	93.0	35.5	21.0	60
16	66.0	...	66.0	26.0	....	66.5	....	35.0	20.5	
15	65.5	...	65.5	25.5	....	65.5	92.5	34.0	20.0	59
14	65.0	...	....	25.0	....	65.0	92.0	33.0		
13	64.5	...	65.0	24.0	....	64.5	....	32.0	....	58
12	64.0	...	64.5	23.5	....	64.0	91.5	31.5		
11	63.5	...	....	23.0	....	63.5	91.0	30.5		
10	63.0	...	64.0	22.0	....	62.5	90.5	29.5	....	57
9	62.0	...	....	21.5	....	62.0	....	29.0		
8	61.5	...	63.5	20.5	....	61.5	90.0	28.0		
7	61.0	...	63.0	20.0	....	61.0	89.5	27.0	....	56
6	60.5	...	....	19.5	....	60.5	....	26.0		
5	60.0	...	62.5	18.5	....	60.0	89.0	25.5	....	55
4	59.5	...	62.0	18.0	....	59.0	88.5	24.5		
3	59.0	...	....	17.0	....	58.5	88.0	23.5		
2	58.0	...	61.5	16.5	....	58.0	....	23.0	....	54
1	57.5	...	61.0	16.0	....	57.5	87.5	22.0		
0	57.0	...	....	15.0	....	57.0	87.0	21.0	....	53

Table 17 ROUGHNESS RATING SCALE*

Roughness symbol	*Root-mean-square height of irregularities*	
	Inches	*Microinches*
63M	0.063	63000
16M	0.016	16000
4M	0.004	4000
1M	0.001	1000
250	0.00025	250
63	0.000063	63
32	0.000032	32
16	0.000016	16
8	0.000008	8
4	0.000004	4
2	0.000002	2
1	0.000001	1
½	0.0000005	½
¼	0.00000025	¼

* Extracted from "American Standard Surface Roughness, Waviness, and Lay" (ASA B46.1-1947), with the permission of the publisher, The American Society of Mechanical Engineers, New York.

Table 18 LAY SYMBOLS*

Direction of the predominant pattern	*Symbol*
Parallel to the line of the surface indicated	=
Perpendicular to the line of the surface indicated	⊥
Angular in both directions to the line of the surface indicated	X
Multidirectional	M
Approximately circular relative to the center of the surface indicated	C
Approximately radial to the center of the surface indicated	R

* Extracted from "American Standard Surface Roughness, Waviness, and Lay" (ASA B46.1-1947), with the permission of the publisher, The American Society of Mechanical Engineers, New York.

Table 19 WAVINESS RATING SCALE*

Waviness scale, in.
0.020
0.010
0.005
0.002
0.0002
0.0001
0.00005

* Extracted from "American Standard Surface Roughness, Waviness, and Lay" (ASA B46.1-1947), with the permission of the publisher, The American Society of Mechanical Engineers, New York.

INDEX

A

Acceptance or sorting inspection, 4
Acme thread, 228
Adjustable limit length gage, 139–140
Adjustable square, 63
Air comparator, 164–170
Air gage, 164–170
Allowance, 49
American Gage Design Standards, 126, 144
American National Standard screw-thread fits, 226–227
American National Standard screw threads, for acme and other translating threads, 228
  for bolts, nuts, and other threaded parts, 225–226
  coarse and fine series, 339
  for pipe, 228
Angle gage, 66
Angle iron or angle plate, 70
Angular measure, 63
Angular measurements, 63–66, 190–218
Arithmetic mean, 325
Assignable causes of variation, 322
Auxiliary view, 14
Average, 324

B

Basic size, 49
  basic hole and basic shaft systems of establishing, 50
Bausch and Lomb contour measuring projector, 186–189
Beam divider, 62
Bench block or bench plate, 69
Bench center, 72–73
Bench gage, 151–152
Best size wires, 240–243
Bevel, 66
Bevel protractor, 64
Bilateral dimensioning, 51
Blueprint reading, 8–25
  problems, 26–40
Brinell hardness numbers, 340
Brinell hardness test, 267–268
Brush Surface Analyzer, 292–294

C

Caliper, 59–62, 91
  firm-joint, 60
  hermaphrodite, 62
  toolmakers' spring, 59
  transfer firm-joint, 60
  vernier, 91
Cathode-ray tube, 313–314
Center gage, 73–74
Center square, 65
Centralized inspection, 5
Chance causes of variation, 322
Classes of fit, 50–51
Clearance fit, 51
Combination set, 65
Combination square, 63
Common fractions, 44–45
CompAIRator air gage, 165–167
Comparator square, 191
Constants for measuring dovetails, 339
Conversion, of hardness scales, 342–346
  of interference bands to inches, 337
Coordinate measurements, 175, 181
Cylindrical square, 191–192

D

Decimal equivalents of binary fractions of an inch, 335
Decimal fractions, 45
Dial caliper gages, 147
Dial depth gage, 149
Dial indicator gage, for inspecting gears, 263, 265
  for inspecting pitch diameter of screw threads, 238
Dial indicators, gages, and comparators, 143–152, 238, 239, 263, 265
Dial micrometer, 149
Dial test indicator, 146–147
Dial thread lead gage, 239
Dimensionair, 170
Dimensioning, 20–23, 51–52
  bilateral and unilateral, 51–52
  systems of, 20–22
  tolerance or limit, 22–23
Divider, 62
Dovetails, measuring, 197
Drawing symbols for screw threads, 18–19, 228
Drawings, assembly and detail, 23–24
  working, 11
Drill gage, 74
Driving fit, 51
Duovec magnetic particle inspection, 300–303

E

Efficiency inspection, 6
Electrical comparators, 154–161
Electrichek, 161
Electrified-particle inspection, 307–308
Electrigage, 162
Electrolimit comparator, 155–157
Electronic comparator, 157–160
Endurance inspection, 6
English-measure graduation on steel rules, 336
English system units of length, 43–44
Expansion fit, 51

F

Faxfilm, 286–287
Feeler gage, 74
Fellows Gear Inspection Instrument, 256–259
Fellows Involute Measuring Instrument, 262–263
Fellows Red Liner, 260–262
File test of hardness, 267
Fillet and radius gage, 66
Filtered particle inspection, 308–310
Finish symbols, 16–18, 283–284
First-piece inspection, 5
Floor inspection, 5
Fluorescent penetrant inspection, 304–306
Fluoroscopic inspection, 318–319
Force fit, 51
Fractions, common, 44–45
  decimal, 45
Frequency distribution, 324–326
Functional inspection, 6

G

Gage, 66, 69–70, 73–74, 81–83, 126–170, 193, 229, 231–234
  adjustable limit length, 139–140
  angle, 66, 93
  bench, 151–152
  center, 73
  dial caliper, 147
  dial depth, 149
  drill, 74
  electrical, 154–161
  Electrolimit, 163–164
  feeler, 74
  "go-not go," 127
  indicating, 143, 147–148
    hole, 148
    snap, 147
  limit, 127
  master, 127
  master disk, 140
  Para-Plane, 121
  plain adjustable limit snap, 137–139
  plain cylindrical plug, 132–133
  plain cylindrical ring, 135–137
  planer and shaper, 83
  screw pitch, 74, 229
  sheet metal, 74
  small hole, 81–82
  surface, 69
  taper-parallel, 83
  telescoping, 81
  thickness, 74
  thread, 231–234
    gage-pin-type snap, 234
    plug, 231, 232
    ring, 231, 232
    roll limit snap, 233–234
  visual, 152–154
  wire, 74
  working, 127

Gagemakers' tolerance, 129–131, 337
Gages, care of, 141–142
  classification of, 127
  wear allowance for, 131–132
Gamma rays, 312
Gear inspection, 246–265
Gear-measuring blocks, 253
Gear-measuring wires, 252
Gear terms, 249–251
Gear-tooth vernier caliper, 252
Gearing, kinds of, 246–249
  systems of, 251–252
"Go-not go" gages, 128

H

Hardened-steel square, 190
Hardness tests, 266–279
  Brinell, 267–268
  file, 267
  Knoop, 275
  Mohs, 266
  Monotron, 275–277
  Rockwell, 269–273
    superficial, 273–274
  Sclerometer, 266–267
  Scleroscope, 277–279
  Vickers, 274–275
Hook rule, 57

I

Indicating gage, 143
Indicating hole gage, 148
Indicating micrometer, 149
Indicating snap gage, 147
Inspection, 1–6, 127, 324
  by attributes, 4, 324
  definition of, 1
  kinds of, 4–6
  organization for, 1–3
  by variables, 4, 324
Inspection department, 3
Inspection practice, suggestions for, 333–335
Inspection problems, 333–334
Inspector, qualifications for, 6–7
Interchangeable and selective assembly manufacturing, 52–53, 126
Interference fit, 51
Interferometer, 108
International temperature for measurement, 46

J

Jones and Lamson optical comparator, 184–186

K

Key-operation inspection, 6
Knee, 70
Knoop hardness scales, 340
Knoop hardness test, 275

L

Lay symbols, 347
Lead of screw thread, 224
Left-hand thread, 225
Length, standards of, 41
Light-wave micrometer, 122
Light waves, measuring with, 43, 115–121
Limit dimensioning, 22–23
Limit gage, 127–129
Limits, 50
Lines, width and character of, 13

M

Magnaflux inspection, 300–303
Magnaglo inspection, 300–303
Magna-Sine, 197
Magnetic particle inspection, 297–303
  Duovec, 300–303
  Magnaflux, 300–303
  Magnaglo, 300–303
Magnifier, 172
Master disk, 140
Master flat, 69
Master gage, 127
Measure Master Machine, 243
Measuring, of dovetails, 197
  with light waves, 43, 114–121
  of tapers, 197–202
Mercury 198, pp. 43, 109
Meter, 42
Metric system units of length, 45–46
Metricator, 170
Micrometer, 76–89, 94–95, 122–124, 149, 230
  bench, 95
  depth gage, 88
  indicating, 149
  inside, 84–86
    jaw-type, 85
    measuring-rod-type, 86

Micrometer, light-wave, 122–124
outside, 76–81, 94–95
screw thread, 230
Micrometers, care of, 84
principle of, 76–79
reading of, 78–79, 87–88, 94–95
Mohs scale of hardness, 266, 340
Monochromatic lamp, 114
Monochromatic light, 114
Monotron hardness test, 275–277
Multichek Electrigage, 162–163
Multiple inspection gages, 162–164, 169
air, 169
electrical, 162–164

N

Nominal size, 48
Normal probability curve, 325

O

One hundred per cent inspection, 4, 327
Optical comparator, 180–189, 235–237
Optical dividing head, 218
Optical flat, 115
Optical parallels, 122
Orthographic projection, 9–10

P

Parallels, 71, 122
iron and steel, 71
optical, 122
Para-Plane gage, 121
Partek filtered particle inspection, 308–310
Performance inspection, 6
Pictorial representation, 8–9
Pilot-piece inspection, 5
Pipe thread, 228
Pipe thread plug gage, 232–233
Pipe thread ring gage, 232–233
Pitch, of gears, 249
of screw threads, 224
Plain adjustable limit snap gage, 137–139
Plain cylindrical plug gage, 132–133
Plain cylindrical ring gage, 135–137
Planer and shaper gage, 83
Pocket comparator, 174–175
Pocket slide caliper rule, 57
Precision gage blocks, 105–112
accessories, 112–114
Precisionaire, 168–169
Profilometer, 282–292
Projection comparator, 180–189, 235–237
Push fit, 51

Q

Quality control, 321–329
Quality-control chart, 322–323
Quality standards, 3

R

Radioactive-isotope radiography, 319
Radiographic inspection, 312–320
Radium radiography, 318
Radius and fillet gage, 66
Range, 326
Red Ring Gear Speeder, 253–254
Red Ring Universal Gear Checker and Lead Comparator, 254–256
Rockwell hardness tests, 269–274
normal, 269–273
scales, 341
superficial, 273–274
scales, 341
Roll thread limit snap gage, 233–234
Root-mean-square value, 282–283, 326
Roughness rating scale, 347
Rule depth gage, 58
Running fit, 51

S

Sampling inspection, 4, 327–329
Scale or steel rule, 56–59
Sclerometer hardness test, 266
Scleroscope hardness test, 277–279
Screw-pitch gage, 74, 229
Screw-thread drawing symbols, 18–19, 228
Screw-thread inspection, 220–245
Screw-thread micrometer caliper, 230
Screw-thread terms, 223–225
Screw threads, 220–245
forms of, 220–223
(*See also* American National Standard screw threads)
Section lining, 16
Sectional drawings, 14–15
Selective assembly, 53
Sheet-metal gage, 74
Shop microscope, 173–174
Shrink fit, 51
Sine bar, 193–197, 200

Sine plate, 196
Sliding fit, 51
Small-hole gage, 81–82
Sonizon, 310–312
Sorting or acceptance inspection, 4
Square, 63, 65, 190–191
  adjustable, 63
  center, 65
  combination, 63
  cylindrical, 191
  hardened-steel, 190
  surface-plate, 191
Standard deviation, 326
Standard Measuring Machine, 99–103
Standards of length, 41
Statiflux electrified-particle inspection, 307–308
Statistical quality control, 321–329
Steel rule, 56–59
Supermicrometer, 96–99, 243
Surface, definition of, 280
Surface Analyzer, Brush, 292–294
Surface finish, 17, 280–294
  drawing symbols for specifying, 17, 283–284
  elements of, 280–281
    flaws, 280
    lay, 281
    roughness, 281
    waviness, 281
  methods of inspecting, 284–294
    Faxfilm, 286–287
    Profilometer, 287–292
    Surface Analyzer, 292–294
    visual and tactile, 284–286
Surface gage, 69
Surface plate, 67–69
Surface-plate square, 191
Systems of gearing, 251–252

T

Taper, 197–199
  computations: formulas, 338
  measuring, 197
Taper parallel gage, 83
Taper plug gage, 198–199
Taper ring gage, 198–199
Telescoping gage, 81
Thickness gage, 74
Third-angle orthographic projection, 10–12
Thread plug gage, 231
Thread ring gage, 231
Thread roll limit snap gage, 233
Threads, screw (*see* Screw threads)
Three-wire system of measuring screw threads, 239–245
Tolerance, definition of, 50
Tolerance dimensioning, 48–51
Toolmaker microscope, 177–180, 237–238
Toolmakers' flat, 69, 115
Toolmakers' microscope, 175–177
Trammel, 62
Transition fit, 51
Translating threads, 228
Trigonometry, principles of, 202–212

U

Ultrasonic testing, 310–312
Unified Standard screw thread, 220
Unilateral dimensioning, 51
Universal angle gage, 193
Universal bevel protractor, 192–193
Universal dividing head, 212–217

V

V blocks, 72
Variation in quality, causes of, 322
Vernier, 89–94
  principle of, 89–90
  reading of, 90–91
Vernier caliper, 91–92
Vernier depth gage, 92–93
Vernier height gage, 93–94
Vickers hardness test, 274–275
Visual gage, 152–154, 243

W

Wear allowance for plain cylindrical plug and ring gages, 131–132
Wilder Micro Projector, 182–184
Wire gage, 74
Working gage, 127
Working inspection, 5

X

X-ray inspection, 313–318

Y

Yard, 41

Z

Zyglo fluorescent penetrant inspection, 304–306

MOTION PICTURES AND FILMSTRIPS

The motion pictures and filmstrips listed below can be used to supplement the material presented in this book. It is recommended, however, that each film be reviewed before it is used in order to determine its suitability for a particular group.

Both motion pictures and filmstrips are included in this visual bibliography, and the character of each one is indicated by the self-explanatory abbreviations "MP" and "FS." Immediately following this identification is the name of the producer and, if the distributor is different from the producer, the name of the distributor. Abbreviations are used for names of producers and distributors, and these abbreviations are identified in the list of sources at the end of the bibliography. In most instances, the films can be borrowed or rented from local or state 16-mm film libraries, a nation-wide list of which is given in "A Directory of 2002 16mm Film Libraries," available for 30 cents from the Superintendent of Documents, Washington 25, D.C. Unless otherwise indicated, the motion pictures are 16-mm sound black-and-white films and the film-strips are 35-mm, black-and-white, and silent.

This bibliography is suggestive only, and film users should examine the latest annual edition and quarterly supplements of "Educational Film Guide," a catalog of some 10,000 films published by The H. W. Wilson Co., New York. The "Guide," a standard reference book, is available in most college and public libraries.

According to Plan (MP, McGraw, 9 min). Demonstrates the need for engineering drawing and its importance as a "language" or means of communication for the coordinated work of the many people involved in modern production.

Auxiliary Views: Double Auxiliaries (MP, McGraw, 13 min). Explains why a single auxiliary view does not give an accurate picture of an oblique face and describes the theory of the double auxiliary or oblique view. Supplementary filmstrip, same title, 26 frames, also available.

Auxiliary Views: Single Auxiliaries (MP, McGraw, 23 min). Reviews the principles of orthographic projection, explains the need for auxiliary projections, and defines and illustrates such projections. Supplementary filmstrip, same title, 38 frames, also available.

The Bevel Protractor (MP, USOE/UWF, 15 min). Principles of the vernier bevel protractor; how to set and read the bevel protractor, and use the protractor to lay out angular work and to check angles. Supplementary filmstrip, same title, 34 frames, also available.

The Cathode Ray Tube: How It works (MP, USN/UWF, 15 min). Demonstrates the construction and function of various parts of the cathode-ray tube. Explains electrostatic and electromagnetic deflection and how varied currents affect the position of the spot of light on the scope.

The Dial Indicator (MP, Federal, 20 min color). Explains the principles of direct and precision measuring, the meaning of tolerances and their application in mass production, and the uses of dial indicators.

Dial Indicator Gages (MP, Federal, 18 min color). Demonstrates how dial indicator gages are used to control the dimension of interchangeable workpieces produced by mass-production methods.

DoAll Gages (FS series, DoAll, sound). Four filmstrips, each with an accompanying recording, 33⅓ rpm, dealing with different aspects of DoAll gages. Titles and playing times of the individual filmstrips are:

DoAll Precision Accuracy with the DoAll Precision Laboratory (28 min)

How DoAll Gages Are Made (7 min)

How DoAll Gages Are Used (18 min)

Theory Behind the Use of DoAll Gages (26 min)

Drawings and the Shop (MB, McGraw, 15 min). Explains the relationship between the making of a drawing and various production operations in shop and factory. Supplementary filmstrip, same title, 43 frames, also available.

Fixed Gages (MP, USOE/UWF, 17 min). Types and uses of gages for precision measurement—snap, ring, plug, taper plug, taper ring, flush pin, and screw plug gages. Supplementary filmstrip, same title, 35 frames, also available.

Gage Blocks and Accessories (MP, USOE/UWF, 23 min). Why accessories are used with gage blocks; how to inspect a plug gage, an adjustable snap gage, a profile gage, a ring gage, and screw-thread pitch; and how to build a height gage and scriber. Supplementary filmstrip, same title, 33 frames, also available.

Hardness Testing: Rockwell (MP, USOE/UWF, 18 min). The need for hardness testing; how to set up the Rockwell Hardness Tester, select and seat the penetrator, select and mount the anvil, adjust the timing of the machine, and test flat and curved-surfaces. Supplementary filmstrip, same title, 49 frames, also available.

Height Gages and Test Indicators (MP, USOE/UWF, 12 min). Principles and parts of the vernier height gage; how to use the gage to lay out holes and to set test indicators; and how to use test indicators to check the accuracy of machined surfaces. Supplementary filmstrip, same title, 34 frames, also available.

Indirect Measurement (MP, KB, 12 min). Explains the need for indirect measurement in certain situations, and demonstrates three methods of indirect measurement—congruent triangles, similar triangles, and trigonometry.

Industrial Measurements (MP, West Elec, 8 min). Traces the use of precise measurements in the manufacture of telephone equipment and, using crystals as an illustration, explains both mechanical and precision measurement.

Inspection of Threads (MP, USOE/UWF, 22 min). How to identify the different parts of an American National Standard Thread, in-

spect external threads with a roll snap gage, adjust the roll snap gage, and inspect internal threads with a plug gage. Supplementary filmstrip, same title, 49 frames, also available.

Light Waves and Their Uses (MP, EBF, 11 min). Explains the principles of reflection, refraction, and interference; and deals briefly with polar screens, the electromagnetic spectrum, and quantum theory.

Magnetism (MP, Coronet, 10 min). Discusses types of permanent magnets, attraction and repulsion, magnet making, fields of force, electromagnets, and the uses of magnets.

Maintaining Quality Standards (MP, USOE/UWF, 10 min). A supervisor learns that quality as well as quantity production is necessary, and how such quality standards can be achieved and maintained.

Measurement with Light Waves (MP, USOE/UWF, 15 min). Principles of measurement with light waves, the nature of light waves, the cause of interference bands and the use of these bands in ultra-precision measurement. Procedures used in gage-block inspection. Supplementary filmstrip, same title, 50 frames, also available.

The Micrometer (MO, USOE/UWF, 15 min). Various types of micrometers; how to use a micrometer, read the barrel and thimble scales, check the accuracy of readings, and take care of the instrument. Supplementary filmstrip, same title, 38 frames, also available.

The Microscope and Its Use (MP, YAF, 10 min). Explains the parts of a microscope used in a typical high school science laboratory, and the basic rules for its operation and use.

Optical Inspection Methods, part 1 (MP, USN/UWF, 26 min). Explains visual methods of inspection, the use of gages, the necessity for checking the gages, and the theory and use of Newton's rings as an inspection method.

Optical Inspection Methods, part 2 (MP, USN/UWF, 19 min). Explains methods of inspection of prisms and spherical lenses, and illustrates the use of the spectrometer.

Orthographic Projection (MP, McGraw, 18 min). Explains by animation the purpose and method of preparing front, side, and top

views of an object. Supplementary filmstrip, same title, 40 frames, also available.

Plain Indexing and Cutting a Spur Gear (MP, USOE/UWF, 26 min). Elements of spur gear teeth; principles of the dividing head; how to set up a cutter for milling a spur gear; use of standard indexing plates; and how to mill gear teeth to a specified depth. Supplementary filmstrip, same title, 53 frames, also available.

Precision Gage Blocks (MP, USOE/UWF, 18 min). Various uses of gage blocks in setting inspection gages; how to calculate gage blocks, and clean and assemble the blocks. Supplementary filmstrip, same title, 28 frames, also available.

Principal Dimensions, Reference Surfaces and Tolerances (MP, USOE/UWF, 12 min). Relationship between the blueprint and a rough and finished casting; how to use a blueprint in selecting reference surfaces; interpret tolerances; and check the accuracy of finished work. Supplementary filmstrip, same title, 25 frames, also available.

Reading a Three-View Drawing (MP, USOE/UWF, 10 min). How to use a blueprint to visualize the object; interpret a blueprint; and make a tool block according to specifications shown on a blueprint. Supplementary filmstrip, same title, 30 frames, also available.

Sectional Views and Projections, Finish Marks (MP, USOE/UWF, 15 min). Dimension, center, cross-section, and object lines; projection of a sectional view; uses of finish marks; and meanings of standard cross-section lines. Supplementary filmstrip, same title, 29 frames, also available.

Sections and Conventions (MP, McGraw, 15 min). Points out the need for sectional views, and explains the meaning of special symbols used in sectioning. Supplementary filmstrip, same title, 44 frames, also available.

Selection of Dimensions (MP, McGraw, 18 min). Explains the principles that govern the choice of dimensions and the factors upon which they are based: functional characteristics of the object and manufacturing methods. Supplementary filmstrip, *Dimensioning Techniques*, 48 frames, also available.

Statistical Quality Control: Acceptance Sampling (MP, USN/UWF,

18 min). Statistical methods employed in acceptance sampling by government inspectors responsible for the acceptance of products.

Statistical Quality Control: Process Control (MP, USN/UWF, 12 min). Shows statistical methods involved in process control used to obtain for the government a better product at a lower price.

The Steel Rule (MP, USOE/UWF, 14 min). How to read steel rules, use flexible hook and rule-type gages, lay out holes with a combination square and scribe them with a divider, and use inside and outside calipers to transfer dimensions to and from steel rules. Supplementary filmstrip, same title, 52 frames, also available.

Tools and Rules for Precision Measuring (MP, Starrett, 30 min). Reviews the history of precision measuring, shows tools and instruments introduced by Starrett, and gives instructions on how to use and read the micrometer and vernier.

Verniers (MP, USOE/UWF, 19 min). Principle of the vernier scale and its application to a micrometer and to inside and outside calipers; how to use and read vernier micrometers and vernier calipers. Supplementary filmstrip, same title, 37 frames, also available.

Visualizing an Object (MP, USOE/UWF, 9 min). How a blueprint is developed; how dimensions are shown by different views; and how special information is indicated on a blueprint. Supplementary filmstrip, same title, 39 frames, also available.

X-ray Inspection (MP, USOE/UWF, 21 min). Use of radiographs in industry; generation of X-rays in the X-ray tube; wave nature of X-rays; procedure in making radiographs; and interpretation of radiographs for defects in metals. Supplementary filmstrip, same title, 54 frames, also available.

Directory of sources

Coronet—Coronet Films, Coronet Bldg., Chicago 1, Ill.

DoAll—The DoAll Co., 254 N. Laurel Ave., Des Plaines, Ill.

EBF—Encyclopaedia Britannica Films, Inc., 1150 Wilmette Ave., Wilmette, Ill.

Federal—Federal Products Corp., 1144 Eddy St., Providence 1, R.I.

KB—Knowledge Builders, 625 Madison Ave., New York 22, N.Y.

McGraw—McGraw-Hill Book Co., Inc., Text-Film Dept., 330 W. 42d St., New York 36, N.Y.

Starrett—The L. S. Starrett Co., Athol, Mass.

USN—U.S. Department of the Navy, Washington 25, D.C.

*Films distributed by United World Films.

USOE—U.S. Office of Education, Washington 25, D.C.

*Films distributed by United World Films.

UWF—United World Films, Inc., 1445 Park Ave., New York 29, N.Y.

West Elec—Western Electric Co., 195 Broadway, New York 7, N.Y.

YAF—Young America Films, Inc., 18 E. 41st St., New York, N.Y.